The University of Jordan
Authorization Form

I, Noor Mustafa AL hashhoosh authorize the University of Jordan to supply copies of my Thesis/Dissertation to libraries or establishments or individuals on request.

Signature:
Date: 10/1/2012

الجامعة الأردنيـــــة
كلية الدراسات العليا

التاريـــخ: / /

نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

أنا الطالب: نـــور مصـــطفى عبـــد الحشـــحوش الرقم الجامعي: (٨٠٨٠١٩٧)
تخصص: الجيولوجيـــا البينيـــة والتطبيقيـــة الكليـــــــة: العلــــــوم

عنوان الرسالة:

GPR AND ARCHAEOSEISMICITY INVESTIGATIONS NEAR THE UMAYYAD MOSQUE IN JERASH CITY, JORDAN.

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

توقيع الطالب: نور الحشحوش التاريخ: ١٠/ ١ / ٢٠١٢

تعتمد كلية الدراسات العليا
هذه النسخة من الرسالــــة
التوقيع...... التاريخ......

GPR AND ARCHAEOSEISMICITY INVESTIGATIONS NEAR THE UMAYYAD MOSQUE IN JERASH CITY, JORDAN.

By
Noor Mustafa Al Hashhoosh

Supervisor
Dr. Najib Abou Karaki, Prof.

This thesis is submitted in partial fulfillment of the requirements for the master's degree of science in Geology.

Faculty of Graduate Studies
The University of Jordan

January 2011

COMMITTEE DECISION

This Thesis/Dissertation (Geophysical and archaeoseismicity investigations near the Umayyad Mosque in Jerash city, Jordan.) was Successfully Defended and Approved on December 8, 2011.

Examination Committee	**Signature**
Dr. Najib Abou Karaki (Supervisor) Prof. of Geophysics	------------------------------
Dr. Elias Salameh (Member) Prof. of hydrogeology and hydrochemistry	------------------------------
Dr. Zuhair H. El Isa (Member) Prof. of Geophysics	------------------------------
Dr. Hani Al-Amoush (Member) Assistant Prof. of Geophysics (Al- albayt University)	------------------------------

Dedication

This thesis is dedicated to my father and mother who taught me that the hardest tasks can be accomplished by determination and ambition.

It is also dedicated to my brothers and sisters, who contributed a spectacular support.

Finally, this thesis is dedicated to my fiancé who has been a great source of motivation and inspiration.

God bless you all

Acknowledgment

I owe my deepest gratitude and biggest thankfulness to my supervisor Prof. Dr. Najib Abou Karaki, for motivating and supporting me through this work, for giving me such an interesting project to do and strengthen me to face all the challenges and difficulties.

I would like to extend my heartfelt gratitude to Geophysicist. Hussam A. Alrashdan (Jordan Seismological Observatory & Geophysical Studies, NRA) for his patience and generous guidance in my field work and for sharing his geophysical experiences specially Ground Penetrating Radar techniques during data collection, processing and interpretation.

I would also like to thank Mr. Abd Almajeed Mujalli, head of Jerash restoration project, for giving me a brief background about the study area.

I am indebted to my great friends Mr. Anas Al-Otaiby and Mr. Mouath Ramthawy, who gave me generous assistance and encouragement during field work. I thank you both for believing in me.

A very special recognition needs to be given to my family and my fiancé for being extremely understanding, for illuminating my path by believing in my capabilities, for their consideration and endless motivation and for their infinite unconditional love and support in everyway possible throughout the process of this thesis and beyond.

I would like to convey thanks to my closest friends, for keeping me going, for their trust and for their endless love.

And my greatest thanks and gratitude to God who made all things possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Figures (continued)

LIST OF ABBREVIATIONS

CMP: Common midpoint

CMPs: Common midpoint surveys

EM: Electromagnetic

GPR: Ground Penetrating Radar

GPS: Global Positioning System

GEOPHYSICAL AND ARCHAEOSEISMICITY INVESTIGATIONS NEAR THE UMAYYAD MOSQUE IN JERASH CITY, JORDAN.

By
Noor Mustafa Al Hashhoosh

Supervisor
Dr. Najib Abou Karaki, Prof.

ABSTRACT

In this thesis ground penetrating radar (GPR) was used, it is an electromagnetic, non-destructive geophysical method used extensively in many different fields. The application of GPR at Umayyad mosque area in Jerash, Jordan, aids the study with a clear subsurface historical conception of this unexcavated site.

The coordinates of the study area were assigned then the area was studied and covered by performing multiple profiles. The profiles were processed, interpreted and finally gathered in images and 3D models that explain the historical sequences and buried archaeological remains.

The archaeological remains of the study area are mainly characterized by partially destroyed walls which were destroyed by a series of earthquakes specially 749 AD earthquake that happened north of Jordan Valley. The remains are related to an ancient Umayyad administrative building.

GPR proved to be one of the most innovative geophysical methods in archaeological surveys, it is important to expand the implementation of this technique much more and use it in wider ranges such as forensics, engineering and environmental remediation.

CHAPTER ONE

INTRODUCTION

1.1 Preface

Ground Penetrating Radar (GPR) is a relatively newly developed geophysical method which can be used as a nondestructive exploration tool for archaeological and paleoseismological investigations at the reconnaissance stage, The GPR technique can also be used in a number of other applications (Bano, 2000) . In this thesis, the GPR technique was used and applied on an archaeological area in Jerash (one of Jordan's main archaeological sites) known to have suffered extensive earthquake related damage (Willis, 1928 and 1933) and (Abou Karaki, 1987). This experiment was carried out in order to examine the efficiency of GPR in this particular kind of environment.

The study area is located in the historical city of Jerash. It is strategically located in the northern part of Jordan on the route connecting Irbid and Amman (Fig 1.1).

1.2 Geographic setting

1.2.1 Location And Accessibility

The investigated area is situated in the northern part of Jordan about 45 km north of the capital city of Amman and about 30 km of Irbid, it can be easily reached from Irbid-Amman highway (road 35) or Al Zarqa highway (road 25). The historical city of Jerash is nowadays surrounded by the modern city of Jerash (Fig 1.2).

The study area is centered on the point of coordinates (32° 16' 43.9" N, 35° 53' 31.5" E) corresponding to World Geodetic System (WGS84) used by Global Positioning System (GPS).

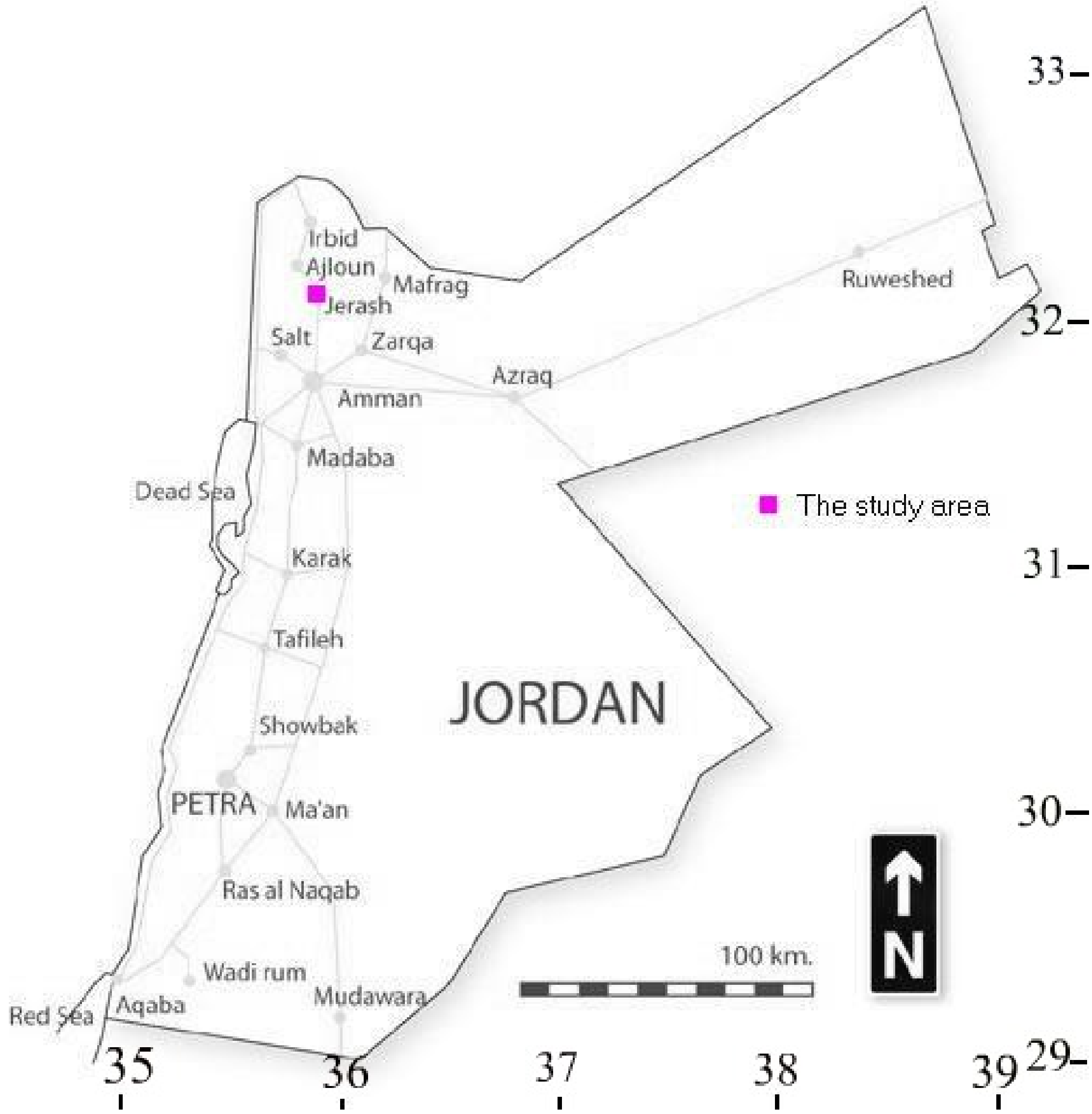

Figure 1.1 The general location of the study area in Jordan. The study area is centered on the point (32° 16' 43.9" N, 35° 53' 31.5" E) situated in Jerash.

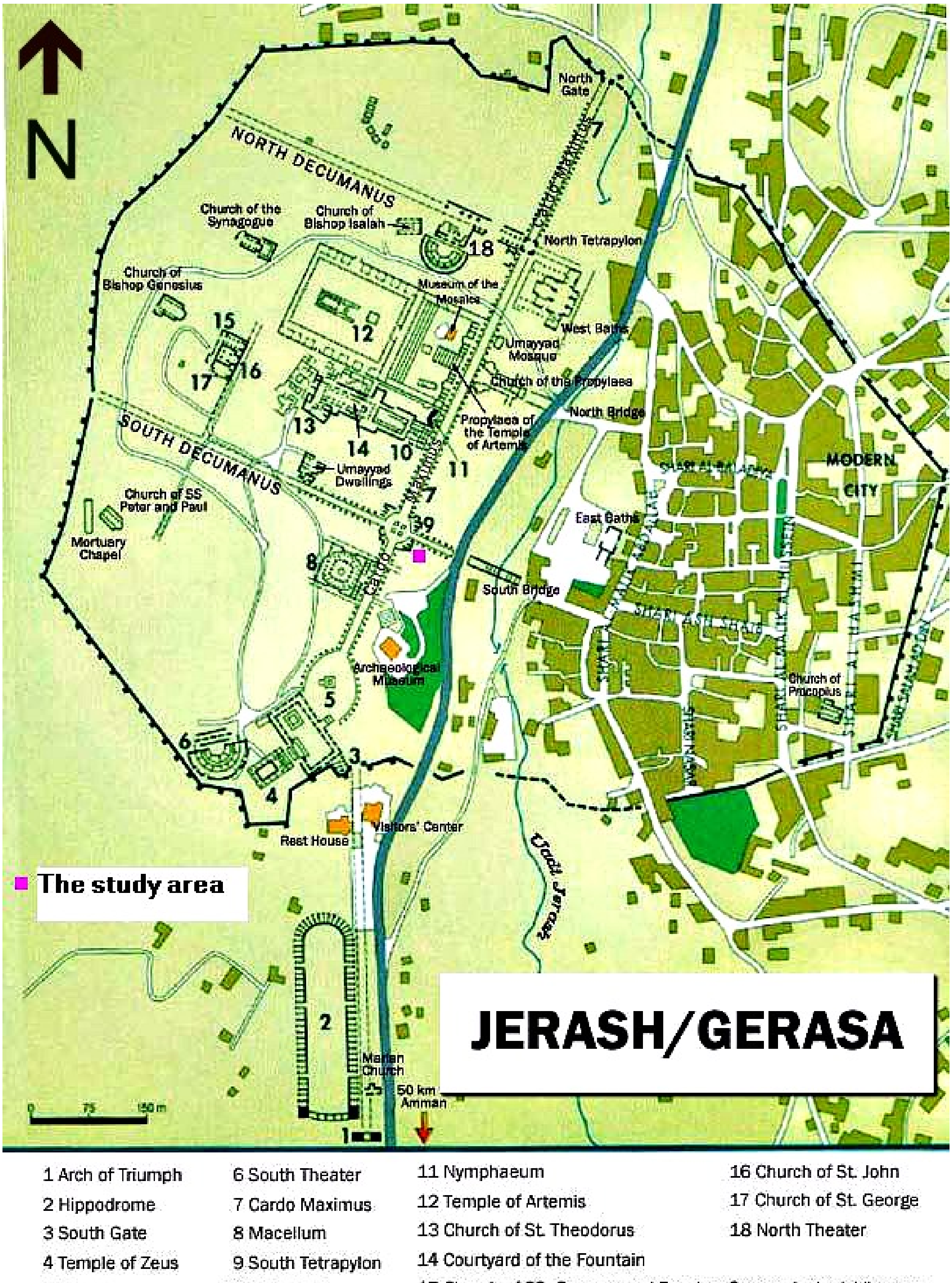

Figure 1.2 The location of the study area (Background map slightly modified from (www.jordanjubilee.com))

1.2.2 Topography

The area is located on a plateau with an average altitude of about 550 meters above sea level, Jerash is known by it's well preserved ruins surrounded by green natural rug in spring time. It lies within the drainage basin of Wadi Jerash, which in turn drains into the Zerqa River to the south of the city of Jarash. The upper reaches of Wadi Jarash drainage basin are relatively steep, and are covered by a mixture of forests, planted orchards and fallow lands (Abu-Jaber et al, 2009).

The elevation range of the province is 300 to 1300 m above sea level with fresh water streams and the Zarqa River flowing through it, surrounded by fertile plains, hills and mountains with a mild Mediterranean climate (Relatively mild winters and warm summers).

The topography is gentle in the historical city specially along the Cardo.

1.2.3 Climate

The climate in general is characterized as Mediterranean semi-arid with two distinct seasons; a long dry hot summer season with a mean monthly temperature of 20°C, extending from May to September and a moderate winter season extending from October to April, with a mean daily temperature of less than 10°C.

In Jerash Governorate, the annual average precipitation ranges between 200 mm in the lower part and 600 mm in the upper part. The rainy season in the study area starts in October and lasts until April, with peak rainfall occurring between December and February. The number of rainy days on average is 40 days per year.

The winter months when soil moisture is replenished by rain have low evapotranspiration rates. Summer months with high potential evapotranspiration rates

have no rain and thus actual evapotranspiration is limited by the availability of soil moisture (Hindawi and Alouni, 2005).

1.2.4 The geology of Jerash

The geology of Jerash was discussed by Abdelhamid (1995). The area is dominated by sedimentary rocks, mainly of Late Cretaceous age. These include in upward sequence the Kurnub Sandstone Group (Lower Cretaceous), the Ajloun Group (Cenomanian–Turonian) comprising the Naur limestone, Fuheis, Hummar, Wadi Shuayb and Wadi As Sir Formations, the Belqa Group comprising the Wadi Um Ghudran and Amman Silicified Formations (Coniacian–Campanian), and small outcrops of the Muwaqqar and Um Rijam chert limestone Formations (Maastrichtian– Eocene).

The characteristics of these formations were described by Bender (1974).

Quaternary sediments and pale brown soil were found in the study area. Building stones are well known historically and archaeologically due to the presence of ancient Roman and Islamic settlements, which stand as evidence of the use of limestone for building purposes (Bashaireh, 2003).

1.3 Objectives and importance of the study

The study area is unexcavated flat area inside the historical city of Jerash. An earlier excavation took place in the western side of this area and unveiled remarkable ruins and walls attached to the Umayyad period.

GPR is a geophysical method that uses electromagnetic waves to detect the subsurface anomalies, the method's capabilities were already shown and proven in a variety of applications. In Jordan the method was used to monitor and solve subsidence related problems (e.g. to detect sinkholes and cavities) in the Dead Sea area (Batayneh et al.

2000), it was also used to detect the fault trace to choose a suitable site for paleoseismicity investigations in Jordan valley (Abou Karaki, 2005).

GPR was used to detect the fault trace prior to paleoseismicity trenching and investigations in the Jordan Valley. GPR field work was done by NRA geophysical team (Abou Karaki ,2005).

The objectives to be achieved are:

1. Identifying the anomalies due to buried ruins in the study area.
2. Defining cultural layers (Documentation of ancient civilizations) in the site.
3. Drawing a detailed reconstruction of the present underground structures.
4. Highlighting the importance of GPR as a relatively new and most innovative geophysical method for the purpose of similar investigation.

1.4 Methodology

Successive steps were planned to perform the survey and obtain the results, these are:

1.4.1 Desk studies

Desk Studies were concerned about:

1. Gathering a full image about the history of the study area, cultural sequences, the surrounding ruins and geographical setting.
2. Collecting data from previous studies relevant to the subject of this thesis, literature review and maps.
3. Delineation of the study area.

1.4.2 Field work

After measuring the coordinates of the study area by a GPS device, and fixing its boundaries, straight and perpendicular lines were drawn to form a reliable **Grid**. The GPR device combined the whole data and produced a file with an extension that could not be opened by the available software (RADAN version 5.0, Geophysical Survey Systems, Inc.).

It was necessary to adapt our methodology, by scanning and interpreting each profile separately then combining the profiles and extracting images & 3D models.

It took eight field trips to collect the most representative data (From November 2010 to April 2011).

1.4.3 Data interpretation

Office work can be summarized as:

1. Processing the obtained data using the suitable software (RADAN Version 5.0 was used), velocity analysis and stacking were performed on the data and the results were turned into images.
2. Interpretation of the data and introducing the results.

1.5 Previous Studies

- Abu Hamideh (1996), in the framework of a master degree thesis done at the department of environmental and applied geology (University of Jordan) under the supervision of Prof. Zuhair El-Isa, described the applications of the geophysical methods (magnetic and resistivity) in archaeology and applied them in Ar Rabba area near the Dead Sea and in Yajouz area.

- Abou Karaki (2005), in cooperation with NRA geophysical teams and geological directory, used GPR technique for determining the impact of large earthquakes on the archeological sites and cultural heritage in the Middle East (Jordan, Lebanon, Syria, and Turkey), in the framework of the EU supported project "APAME".
- Al Ruzouq, et al. (2011) studied the Dead Sea shoreline using GPR method.
- Bano (2000) tested GPR techniques in comparison with seismic profiles while Bano et al (2001) conducted Ground-penetrating radar GPR experiments on a Quaternary sediments made up of gravel, sand and loess to image the structures and tectonic features.
- Cezar. et al. (2001) applied GPR at two archaeological sites situated in Brazil.
- Cukavac, et al. (2008) used the ground penetrating radar to reconstruct buried objects in Brestovik (Serbia).
- Daniels (2000) discussed the fundamental principles of GPR method.
- Hruska and Fuchs (1999) used GPR method in ancient Ephesos (Turkey), the results served a guideline for the subsequent excavations in the area.
- Langfur (2011) discussed the history of Jerash.
- Leif, et al. (1983) described the physical background of GPR and presented few examples of georadar investigations.
- Orlando and Soldovieri (2008) applied two different processing methods of the georadar data in order to improve the results of bad quality data.
- Walmsley discussed the Islamic period and the available archaeological features related to that period in the historical city of Jerash in several annual reports (2002 to 2010).

CHAPTER TWO

GROUND PENETRATING RADAR (GPR)

2.1 Introduction

As ground-penetrating radar (GPR) has gained an ever growing number of users, its range of applications for archaeological mapping are increasing as well.

The GPR method showed its capabilities in a variety of applications, among which the archaeological prospection, besides being a non-invasive technique, it generally allows to identify anomalies due to inclusions or voids in the shallow layers (Conyers, 2006).

Although the method is still the most complex of the near-surface geophysical methods for archaeological mapping, its complexity is now one of its strengths. GPR reflection data are measuring both magnetic and electrical properties of the ground while using multiple frequencies of energy within a three-dimensional cube of data.

Each of those variables are potentially measuring something about the material in the ground. But only when each can be identified in the database, resolved using processing software and then made into images that the human brain can process, they become useful (Conyers, 2006).

2.2 General description

GPR is an electromagnetic (EM) method that detects interfaces between subsurface layers of different physical properties.

GPR uses the principle of scattering of electromagnetic waves to locate buried objects.

The basic principles and theory of operation for GPR have evolved through the disciplines of electrical engineering and seismic exploration, and practitioners of GPR tend to have backgrounds either in geophysical exploration or electrical engineering. The fundamental principle of operation is the same as that used to detect aircraft overhead, but with GPR that antennas are moved over the surface rather than rotating about a fixed

point. This has led to the application of field operational principles that are analogous to the seismic reflection method (Daniels, 2000).

GPR data are usually collected along closely spaced lines within a grid. It is an active method that transmits repetitive short-duration electromagnetic pulses from antennas on the surface into the ground, and then calculates the elapsed time between the transmitted and the received pulses (Called Two-Way Travel Time (TWTT), an expression that is also common in seismic reflection).

The radar pulses penetrate into the layers underground, wherever subsurface dielectric properties change due to variations in underground composition, the transmitted electromagnetic pulses are reflected back to the surface and detected by the receiving antenna. By knowing the travel times of the EM pulses and their penetration velocity, depth in the ground can be accurately measured. (Fig 2.1).

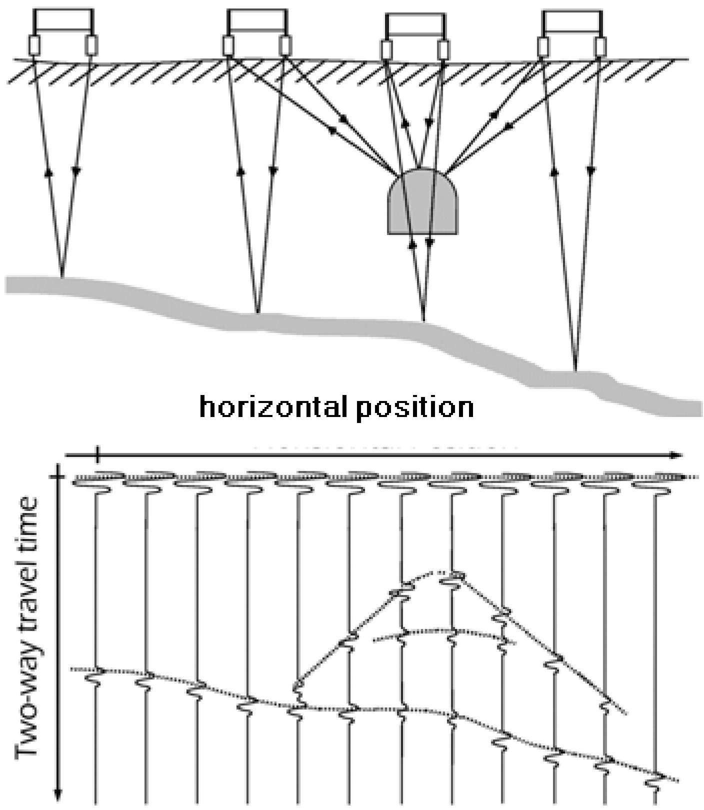

Figure 2.1 GPR technique with wave propagation from transmitter antenna and reflection to the receiver antenna. (www.malags.com)

The depth to which radar energy can penetrate depends on:

- The characteristics of the ground.
- The frequency of the antenna.

Subsurface features, which may cause reflections, are for instance:

- Natural geologic conditions such as voids, changes in soil properties, ice, ground water level, boulders.
- Man-made objects including all types of utilities of various materials which may be considered as anomalies such as pipes, plastics, underground storage tanks, building foundations, buried waste.

When many traces are stacked next to each other, a 2 dimensional vertical profile is produced along the transect. Thousands of reflection traces in many profiles within a grid can then be analyzed to produce both 2 and 3 dimensional images of what lies below the surface.

When reflections occur from buried discontinuities, they are usually created by changes in the electrical or magnetic properties of the rock, sediment or soil, variations in their water content, lithologic changes, or changes in bulk density at stratigraphic interfaces.

Reflections are also generated when radar energy passes through interfaces between anomalous archaeological features and the surrounding matrix. Void spaces in the ground, which may be encountered in burials, tombs, tunnels or pipes, will also generate significant radar reflections because of a similar change in radar wave propagation velocity. Many bed boundaries and other discontinuities will reflect energy back to the surface to be recorded. A composite of reflected energies are recorded from many depths in the ground to produce a series of reflections generated at one location, called a reflection trace (Fig 2.2).

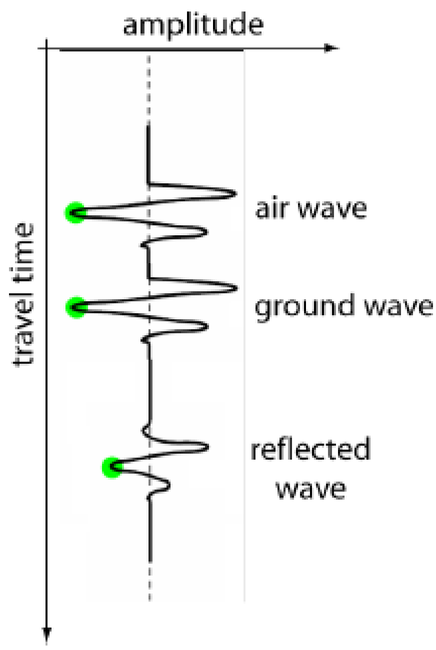

Figure 2.2 GPR trace (Ludwig et al, 2011)

In GPR context the following terminology is often used:

- **Sample**: the incoming signal (to the receiving antenna) is measured a certain number of times per unit of time. A defined number of samples are used to construct a trace.
- **Trace**: specific number of samples are collected at each point of measurement along the profile, these samples make up a trace.
- **Profile**: a collection of traces along a line or transect.
- **Direct wave**: the part of energy that travels the shortest distance between the transmitter and the receiver.

When collecting a sample, GPR device (X3M system) sends a timing signal (a control signal) to the transmitter and receiver antenna respectively. After the transmitter has received the signal, it generates and transmits radar pulses through the antenna.

The pulse then propagates through the medium. Reflections occur from underground objects, structures and materials where there is a change in the electrical property.

Once the receiver has detected the control signal, it collects a sample and passes it to the device. By repeating this process at very finely controlled intervals, the device can collect all the samples in a trace. The device places each incoming sample in its correct position in the current trace. When the trace is complete, it is sent to the computer where it is saved on the hard disk and displayed on the computer monitor.

During data collection, the whole system is transported along the line to be investigated, while collecting and recording traces at defined distance or time intervals. The result is a continuous profile, a record of subsurface conditions along that line (Fig 2.3), a so-called **Radargram** (Malå's manual).

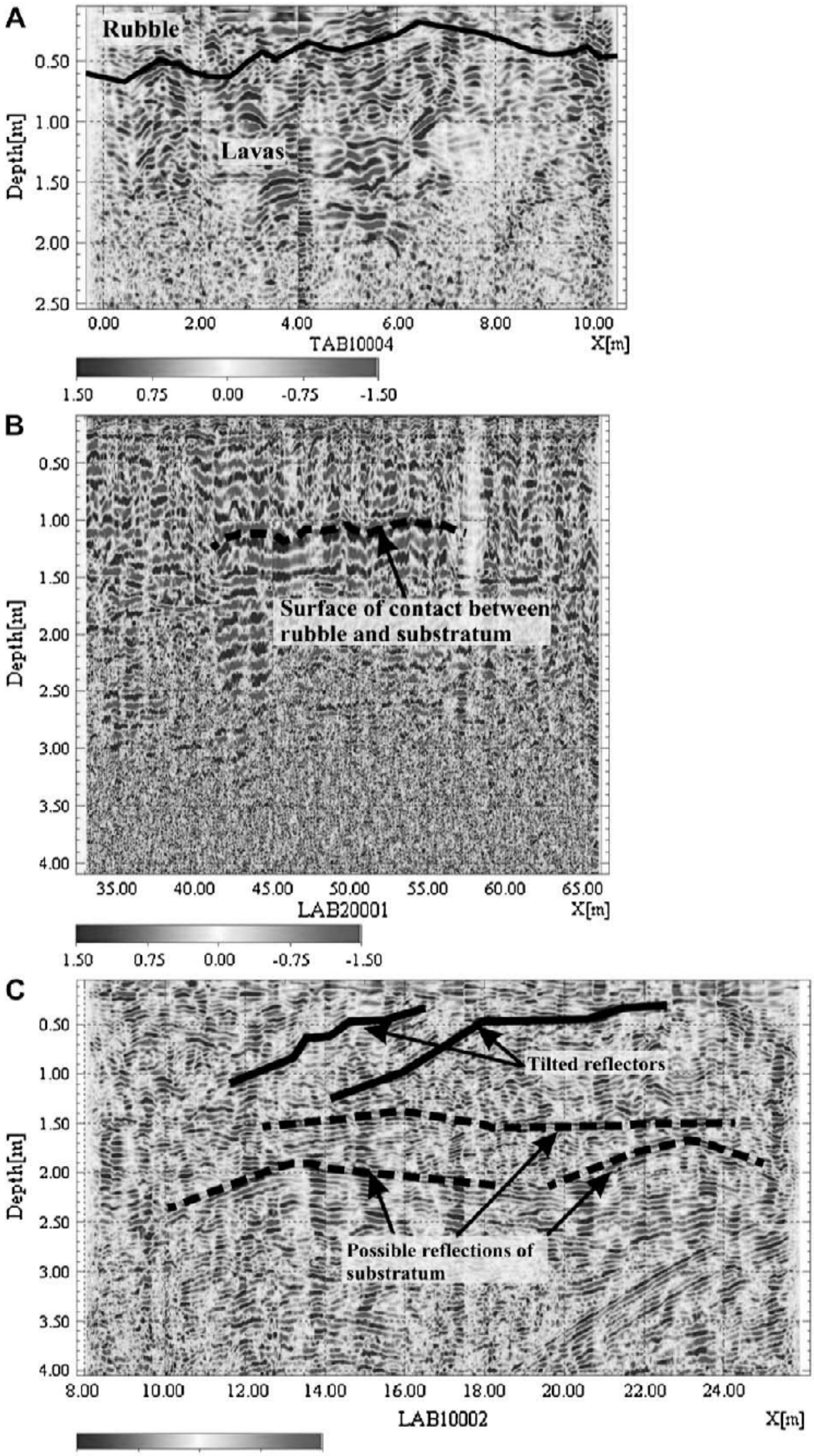

Figure 2.3 Examples of Radagrams profiles (Castellaro et al., 2008)

2.3 Basics in investigation depths and velocities

Sufficient penetration depth may be achieved but it may require a low frequency that reduces the resolution. Range is defined as the distance at which a target can be detected. Resolution on the other hand is defined as the smallest size an object or thinnest layer that may be detected. There often is a compromise regarding the choice of antenna frequency for a particular application at a specific site (Malå's manual).

Electromagnetic waves travel at a specific velocity that is determined primarily by the permittivity of the material. The relationship between the velocity of the wave and material properties is the fundamental basis for using GPR to investigate the subsurface. To state this fundamental physical principle in a different way: the velocity is different between materials with different electrical properties, and a signal passed through two materials with different electrical properties over the same distance will arrive at different times (Daniels,2000).

The depth and resolution requirements and the soil conditions at the site determine the choice of antenna frequency (Table 2.1).

Table 2.1 Approximate depth ranges for different antenna frequencies (www.malags.com).

Antenna frequency (MHz)	**Lower limit of object target size (m)**	**Approximate depth range * (m)**	**Approximate max penetration depth (m)**
25	1	5-30	35-60
50	0.5	5-20	20-30
100	0.1-1	2-15	15-25
250	0.05-0.5	1-10	5-15
500	0.04	1-5	3-10
800	0.02	0.4-2	1-6

*In normal geological environment absence of materials with low resistivity.

A comparison of three different antenna frequencies is shown in Figure 2.4

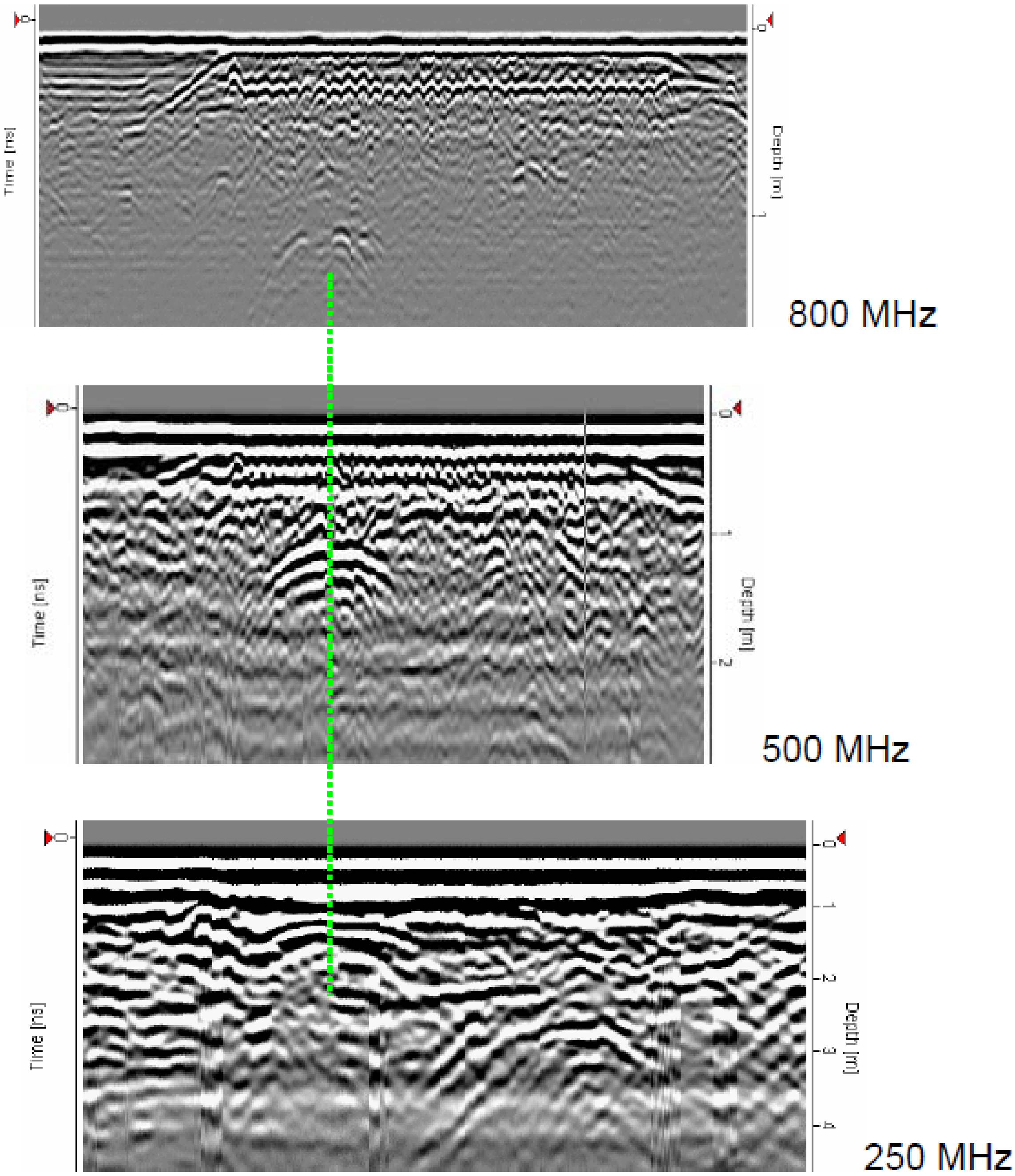

Figure 2.4 Comparison of three different antenna frequencies. The green line marks the position of the same object in the three radargrams, at a depth of approximately 1 m. (www.malags.com)

2.4 Physical background

For all methods working in the time mode, knowledge of wave velocity is necessary. If the velocity is known, it is possible to determine the distance (The depth) (Leif et al, 1983).

The equation for distance is:

$$\mathbf{S = (v.twt)/2}$$

Where

S = distance (m)

V = velocity of the wave (m/s)

Twt = two way travel time

In air the radiowave velocity is known to be equal to the velocity of light. In all other known media it is lower. For radiowaves, the velocity in a given medium had a relation to the velocity of light according to the following equation:

$$\boldsymbol{\varepsilon r = (c/v)^2}$$

where

εr = relative permittivity

c = velocity of light (3 * 10^8 m/s)

v = radiowave velocity in the medium (m/s)

εr is dimensionless and earlier research has shown that there is a strong relation between εr and the water content in the material. Properties such as soil type, pressure and temperature have only a little influence on εr (Leif et al, 1983).

Different soil and rock material usually have a certain water content in the same environment. For rock material, mineral composition is also important for wave

behavior. In ore-bodies for example, which are very electrically conductive, a very strong attenuation of the radio-wave energy occurs (Leif et al, 1983).

Table 2.2 can be used as a guidance, with an approximate velocity values, which can vary greatly with water content in the medium. The larger value given for velocity applies to unsaturated conditions.

Table 2.2 Approximate values of εr (relative permittivity) and the corresponding velocity. (www.malags.com)

Medium	**εr**	**Velocity [m/µs]**
Air	1	300
Fresh water	81	33
Limestone	7 – 16	75 – 113
Granite	5 – 7	113 - 134
Schist	5 - 15	77 – 134
Concrete	4 – 10	95 – 150
Clay	4 – 16	74 – 150
Silt	9 – 23	63 – 100
Sand	4 – 30	55 – 150
Moraine	9 – 25	60 – 100
Ice	3 – 4	150 – 173
Frozen soil	4 – 8	106 – 150

2.5 An overview of the parts of the GPR device

X3M system from MALÅ was used in field investigations, it is consisting of the following parts :

1. RAMAC X3M :

The integrated radar control unit is compatible with MALÅ 100, 250, 500 and 800 MHz shielded antennas, the X3M is designed to fit directly onto the antenna.

2. Shielded antennas:

Shielded antennas are designed to be used in urban areas or sites with a lot of background noise. A shielded antenna consists of both transmitter and receiver in a single housing. The design ensures that the transmitted energy is only emitted from the bottom of the antenna housing, where it is in contact with the ground and protects the receiver from external noise signals.

MALÅ's range of shielded antennas can be operated with the X3M control unit.

- **100 MHz**

The shielded 100 MHz antenna is the lowest frequency shielded antenna. It is used for medium to low resolution investigations.

Dimensions : 1.25 x 0.78 x 0.20 m - Weight: 25.5 kg.

- **250 MHz**

The shielded 250 MHz antenna is a general purpose antenna, generally used for investigations that require medium depth penetration and medium resolution.

Dimensions : 0.74 x 0.44 x 0.16 m – Weight: 7.85 kg.

- **500 MHz**

This is the most popular GPR antenna and offers good resolution for shallow to medium depth investigations.

Dimensions : 0.50 x 0.30 x 0.16 m – Weight: 5.0 kg

- **800 MHz**

The shielded 800 MHz antenna offers high resolution for shallow depth investigations.

Dimensions : 0.38 x 0.20 x 0.12 m – Weight: 2.6 kg.

Shielded antennas have a wide range of frequencies and applications as seen in table 2.3.

Table 2.3 Shielded antennas, suitable areas of use and applications. (www.malags.com)

100 MHz	The shielded 100 MHz antenna is the lowest shielded antenna frequency commercially available. It is used for medium to low resolution. Suitable for geological and geotechnical applications.
250 MHZ	The shielded 250 MHz antenna is a general-purpose antenna. It is used for medium penetration depth and medium resolution. It is commonly used for utility detection, Underground Storage Tanks and void detection.
500 MHz	The shielded 500 MHz antenna is probably the most popular general purpose GPR antenna ever built. It delivers medium to shallow penetration and good resolution. Most commonly used for utility detection, road surveys and archaeological investigations.
800 MHz	The shielded 800 MHz antenna delivers very good resolution for shallow investigations. The interchangeable electronics makes the 800 MHz antenna an economically good alternative to the high resolution 1 GHz antenna. Commonly used for road mapping and concrete investigations.

3. XV monitor

A data acquisition platform and user interface for MALÅ GPR systems.

The Monitor is optimized for the job in hand, i.e. the collection, handling, processing, and presentation of GPR data.

3. MALÅ distance measuring wheel 300 mm:

The measuring wheel can be used for distance control for surveys on flat terrain or in urban areas. The measuring wheel is attached directly on the shielded antenna.

A distance calibration file is used to convert the number of pulses to the correct distances (Fig 2.5).

Figure 2.5 Measuring wheel mounted on the shielded antenna 100 MHz.
(www.malags.com)

2.6 Data collection and processing

By moving the shielded antennas along the ground in transects, GPR reflections can be collected. One antenna transmits the propagating radar waves and the second antenna records the reflection traces generated from below. Stacking hundreds or even thousands of reflection traces together in the transect produce a **reflection profile**.

Usually antennas are placed directly on the ground or close to it, to prevent the dispersion of energy or to minimize the total reflections from the ground surface.

GPR surveys are most often done by establishing a rectangular grid over the desired area. Digital reflection data from a rectangular grid can easily be exported to computer display and imaging processing programs that are pre-set for this gridding method.

In this way the data can be quickly processed and interpreted without time consuming transect surveying and drafting. In addition, with a rectangular grid, important reflections in each profile can be immediately correlated to others and reflections can be tied to parallel or perpendicular transects throughout the grid (Conyers, 2004).

In all cases a sketch of the grid, with notes on the transect length, orientation and beginning and end locations should be noted. The antenna is pulled along transects within the grid. Transects are typically spaced about 25 to 200 cm apart, depending largely on the antenna frequency being used and the amount of coverage desired. Time and financial restraints are also common factors affecting collection procedures, since smaller transect spacing will require more surveying time.

The most tedious, but also important, part of a survey is performed by the person pulling the antennas. This job is the most difficult during continuous data acquisition because the person pulling the sled must not only walk backward but must also make sure that the antennas are moving parallel to the designated transect line. Some people use a cart or other devices to move equipment across the ground (Conyers, 2004).

An important aspect of moving the antennas along the ground is making sure that the antennas are in the same orientation and the same distance above the ground, or directly touching it at all times. Changes in antenna orientation with respect to the ground will potentially cause variations in the recorded reflections that can be confused with “real” changes in the ground.

We can get point-source reflections that are generated from one distinct point feature in the subsurface. The buried materials that generate these types of point-source reflections could be individual rocks, metal objects, pipes that are crossed at right angles, and a great variety of other smaller objects of this sort. They are visible in two-dimensional profiles as reflection **hyperbolas**.

Point surface reflection hyperbolas are generated because most GPR systems produce a transmitted radar beam that propagates the subsurface in a conical pattern, radiating outward as energy travels with depth. The pattern of energy dispersal will therefore spread out and be reflected from buried features that are often not located directly below the transmitting antenna (Conyers, 2004).

The ability to resolve buried features is mostly a function of the wavelength of energy reaching them at the depth they are buried. The minimum object size that can be resolved is about 75% of the downloaded wavelength reaching them. Downloading of radar energy always occurs when energy passes in the ground and decreases in frequency. For instance, a 400 MHz center frequency antenna will generate downloaded energy of about 300 MHz in the ground.

Features which can be resolved, include :

1. Planar surfaces, which can be stratigraphic and soil horizons or large flat archaeological features such as house floors. Elongated buried features of this sort would usually have to be oriented perpendicular to direction of antenna travel in order to be visible on GPR profiles, and would be visible as distinct “point sources” with noticeable reflection hyperbolas.

2. Point targets are features such as tunnels, voids or any other non-planar object.

A common complication that affects resolution of reflections in the ground is background noise, which is almost always recorded during GPR surveys. Ground-

penetrating radar antennas employs electromagnetic energy of frequencies that are similar to those used in television, FM radio and other radio communication bands, so there is almost always nearby noise generators of some kind (Conyers, 2004).

The following steps must be considered that will allow the best subsurface resolution at any investigation site:

1. Obtain as much information as possible about the electrical and magnetic properties of the soil and the sediment in the site.

2. Define the depth of the prospective target features and their approximate composition and direction.

3. Decide whether or not it is possible to use the selected antenna frequency at the site. Study the transportability to and from the site.

4. If it is known that there is a substantial amount of radio interference present at a site, and if the source can be identified, then it may be appropriate to choose an alternate antenna frequency so as to minimize that influence. In general this is not a simple task because it is difficult to identify sources and the risk of compromising survey objectives exists if the wrong antenna is chosen for only this reason (Conyers, 2004).

Unfortunately, it is often not known in advance what the target depth of archaeological features of interest is, their dimensions, or often the ground conditions. Most importantly, the ability to transmit radar energy to the depth necessary is often not known until one actually collects some reflection profiles. Often the best one can do prior to going to the field is to make some rough calculations from the best knowledge available, and take the antennas that will probably be necessary for the task. Antenna choice can therefore be a difficult decision. As a general rule, if the target features are

within about one meter of the ground surface, antennas between 400 and 900 MHz will be adequate to transmit energy to that depth and resolve most features, and associated stratigraphy. (Conyers, 2004)

RADAN Version 5.0 was used for processing, the profiles were transferred to the computer and then each profile was done separately, from the options list **Stacking** was chosen and then **velocity analysis** was performed.

- **Stacking**: The stacking of reflection traces, done with a horizontal filter, or spatial filter (sometimes termed horizontal smoothing), can be applied prior to data acquisition or later during processing (Conyers, 2004). This data manipulation method arithmetically averages digital values of successive reflection traces so that one composite trace is recorded every certain distance along a transect (Conyers, 2004). Many GPR systems allow the operator to manually adjust the stack rate to any integer. This process will average sequentially any number of programmed traces, recording only the average from each of these sequentially, usually as a running average (Davis and annan 1989). This type of horizontal filtering of sequential traces will effectively remove waveforms that may have been generated from surface irregularities such as small bumps or dips in the ground surface (Fisher et al., 1992). It also filters out the effects of velocity changes due to minor water saturation changes, small rocks or voids in the subsurface, and changes in amplitude due to antenna coupling differences with the ground. Stacking is usually a good idea when the antennas are collecting in continuous mode and are moving at fairly slow speed (at an average human pace or less), and when fairly large features in the ground are the target (Conyers, 2004).

- **Velocity analysis and depth conversion**: In order to convert the sections (profiles) to a depth scale, which is required for realistic interpretations and the application of elevation corrections, an accurate estimate of the average subsurface

velocity must be obtained, common midpoint surveys (CMPs) and/or hyperbolic velocity analysis. Most processing programs allow the user to manually input a uniform velocity value or create a velocity profile versus two-way travel time from the hyperbolic matching data. Velocity profile information can usually be imported from the CMP analysis via a suitably formatted text file. Sections are then converted to a depth scale and stretched visually to match the variation in velocity with depth (Jol, 2009).

After choosing the best color theme, all profiles were saved and turned into images.

2.5 Variables affecting GPR penetration and resolution

The success of GPR surveys in archaeology is to a great extent dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial, surface topography and vegetation. It is not a geophysical method that can be immediately applied to all geographic or archaeological settings, although with thoughtful modifications in acquisition and data processing methodology, GPR can be adapted to a great variety of site conditions.

The physical properties that affect the radar waves when they travel through a medium are magnetic permeability and electrical conductivity. Dielectric soils, sediment or rocks will allow the passage of a great amount of electromagnetic energy without dissipating it. The more electrically conductive a material, the less dielectric it is, and energy will attenuate at a much shallower depth. Increasing electrical conductivity mean decreasing penetration. Knowledge of the structure of overburden gives the key for understanding and prediction of natural and man-made changes or risks in future.

Any soil or sediment that contains soluble salts or there are electrolytes in the ground water will create a medium with a high electrical conductivity. In these types of soils radar energy will become attenuated at a shallow depth.

Any mineral in the ground that dissolves in water will create free ions that increases the electrical conductivity and the attenuation of radar energy at shallow depths.

In some calcareous wet sediments or soils, the maximum depth of GPR penetration in the ground can be much less than a meter, no matter what frequency was used.

Magnetic permeability also affects radar penetration in a medium. It is a measure of the ability of a substance to absorb magnetic flux. Most sediments and soils are slightly magnetic and therefore usually have low magnetic permeability. The higher the magnetic permeability, the more electromagnetic energy will be attenuated during the transmission. Media that contains magnetite minerals, iron oxides or iron-rich soils can all have a high magnetic permeability and therefore transmit radar energy poorly.

Radar energy will not penetrate metal. A metal object will reflect all of the radar energy that strikes it and will “shadow” anything directly underneath. Buried metal objects are easy to see in GPR reflections, (Conyers, 2004).

CHAPTER THREE

HISTORICAL REVIEW

3.1 Introduction

Jerash, an ancient and modern city, lies in a quiet valley in the north of Jordan.

The historical city was one of the ten cities of the Decapolis, which refers to the Roman Empire.

3.2 Brief history

Jerash city has a significant importance in the ancient history of Jordan. The ancient town of Jerash (Gerasa or Jarash) is located in Jordan and has a remarkable record of human settlement since the Neolithic (New Stone Age) times.

Few ancient towns are as complete and well-preserved as Jerash, a city complex that once was a thriving commercial zone and part of the Decapolis. Built in the 2nd century BC, the city was conquered in 63 BC by the Roman general Pompey (Al-Hanbali et al., 2005).

This historical city recorded sequence of civilizations since 2500 B.C. The ruins, related to the Greco-Roman city of Gerasa, are the most obvious & interesting ruins, the Roman insured peace and security in the area, which enabled people to devote their efforts to develop and encourage civil development. The Persian invasion caused noticeable decline of Jerash. However, the city continued to flourish during the Umayyad period. The major AD 749 earthquake destroyed many of the temples and buildings, and as no one afford to rebuild or even clear them, they were left exactly as they fell. Excavations and restorations of Jerash had been continuous since 1920s.

Jerash is one of the largest and most well preserved sites of imperial Rome ruins that include :

- The main 800 meter long Cardo (The long Colonnaded street)
- The Triumphal Arch (Hadrian's Arch)
- The two great temples (Zeus and Artemis)
- The wide oval forum
- The two theatres (the large south theatre and small north theatre)
- The Corinthium columns
- A stadium for horse racing called the circus (Hippodrome)
- Two baths
- An almost complete circuit of city walls
- Exceptional fountains

3.3 An overview of the earlier excavations in the study area

Some parts of the historical city of Jerash are still buried and covered by sediments, excavations in the mosque area were undertaken between 2002 and 2010, the overall style of the building complies with the Arab Courtyard type, the mosque was probably built in AD 724- 743.

Investigations were extended to the opposite eastern side, southeast of the south Tetrakionion. A line of shops built along the north-south thoroughfare (Cardo) and contemporary with the mosque was further explored (Fig 3.1). The investigation revealed a subdivision of the shops into smaller rooms, where one of the shops containing several smaller areas in which the remains of a large in-situ storage jar was uncovered as well as 5 intact smaller ceramic vessels (Walmsely, 2006).

Figure 3.1 The partially excavated western side of the study area

Geophysical investigations were needed in this area in order to give previews of the subsurface conditions in order to optimize the archaeological excavations.

CHAPTER FOUR

RECONSTRUCTION OF BURIED OBJECTS USING GPR TECHNIQUE

4.1 Introduction

The main Umayyad mosque of Jerash, which is located to the southwest of the south Tetrakionion, was discovered in 2002. Subsequent investigations were performed after that, including partial excavations to the southeast of the south Tetrakionion, the excavations and partial restorations of this part were performed by a Danish team under the supervision of Alan Walmsely, University of Copenhagen.

4.2 Location

The investigated area is situated to the southeast of the south Tetrakionion (Fig 4.1), it is related to Umayyad mosque across the cardo.

Small rooms and walls were partially exposed in the west side of this area by The Faculty of Humanities of the University of Copenhagen and supported by the Department of Antiquities of Jordan.

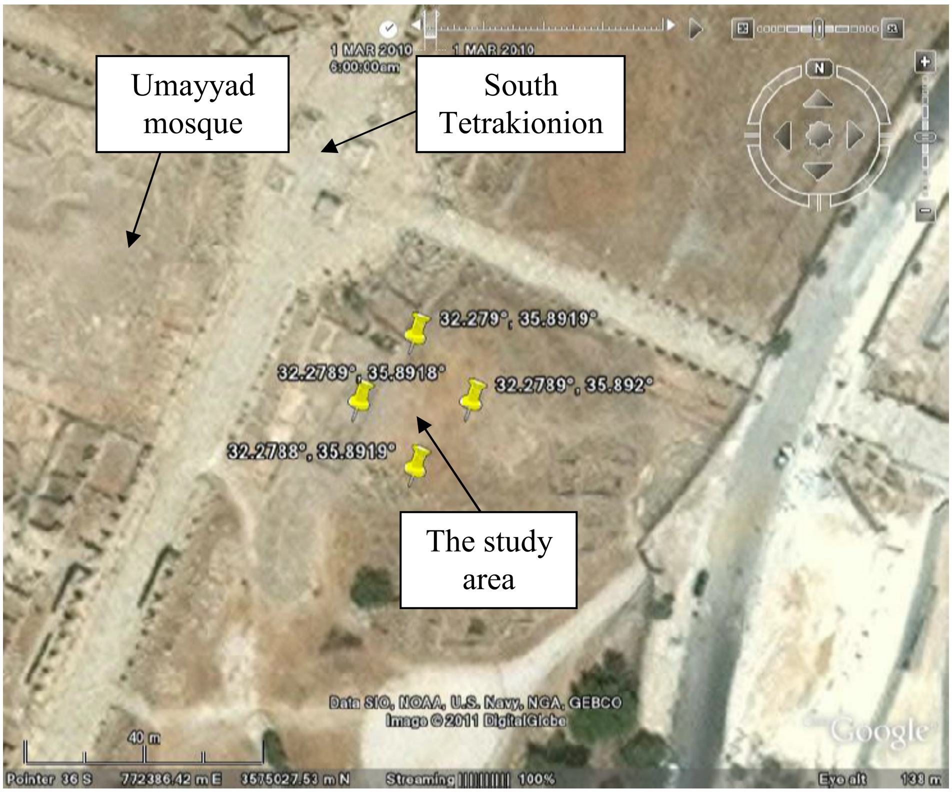

Figure 4.1 The location map

4.3 Field work

One field trip was conducted for the delimitation of the boundaries in the study area and the GPS coordinates were recorded, then it was followed by another field trip to plan and implement the way of collecting GPR data, i.e. drawing North-South parallel straight lines crossed by East-West lines to form an expressive grid (Fig 4.2).

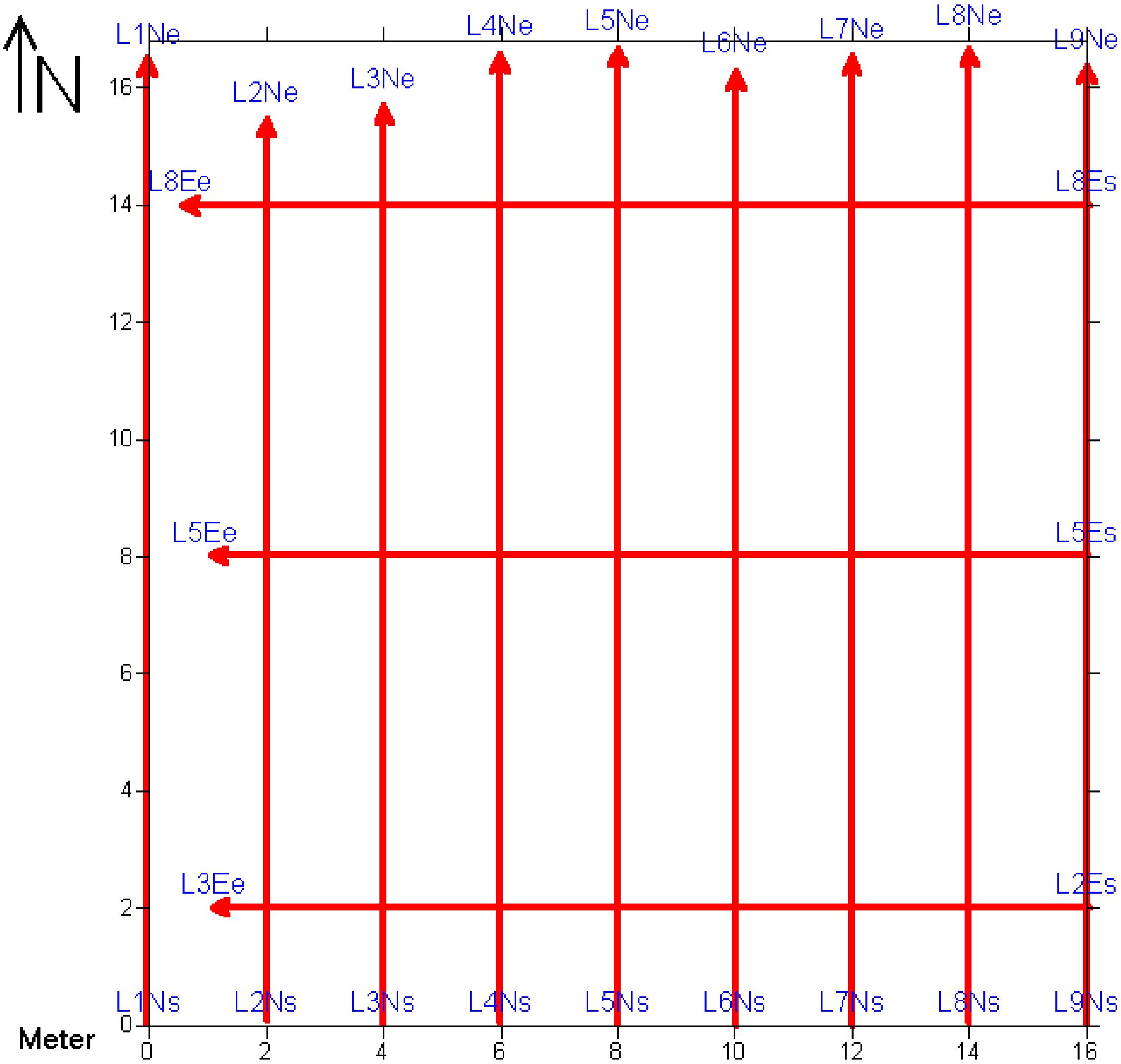

Figure 4.2 Grid plan for the study area, 100 MHz survey

During field investigations, nine south to north and nine east to west profiles were scanned in a 16* 16m grid. The radar data were displayed on the monitor and then saved for the processing stage.

All eighteen profiles were processed using RADAN version 5.0, only twelve profiles were chosen for the interpretation, nine profiles from south to north were taken along 16 meters with 2 meters separation (L1N to L9N) and three profiles from east to west were taken (L2E, L5E, L8E), The result was an inclusive grid that covers the study area (Fig 4.2). The remaining profiles were skipped, because they didn't have major and valuable anomalies to discuss. Few surface metals were marked during the investigation and they were neglected in interpretations.

During field work, X3M system was easy to assemble and operate. XV monitor offers a fast way of parameter choices through factory default settings and automatic identification of the antenna used, it is operated using dual function turn-push button to control the measurements.

4.4 Data Processing and Interpretation

The GPR data is normally displayed with position (distance) along the horizontal axis and time (or approximate depth, if the velocity in the material is known) on vertical axis (Al Ruzouq et al., 2011).

The following figures show the preliminary results for our research.

- Figure 4.3 shows the first GPR profile obtained in the area (16.5 m long). As seen, distance is displayed along the horizontal axis and depth on vertical axis (Both measured in meters). The anomaly between distance 5.30m and 8.08m represents a buried wall located approximately under 0.40m depth. Another anomaly occurs in 15.70m distance at the same depth, this could be another wall. At 2m depth, floor level was found.

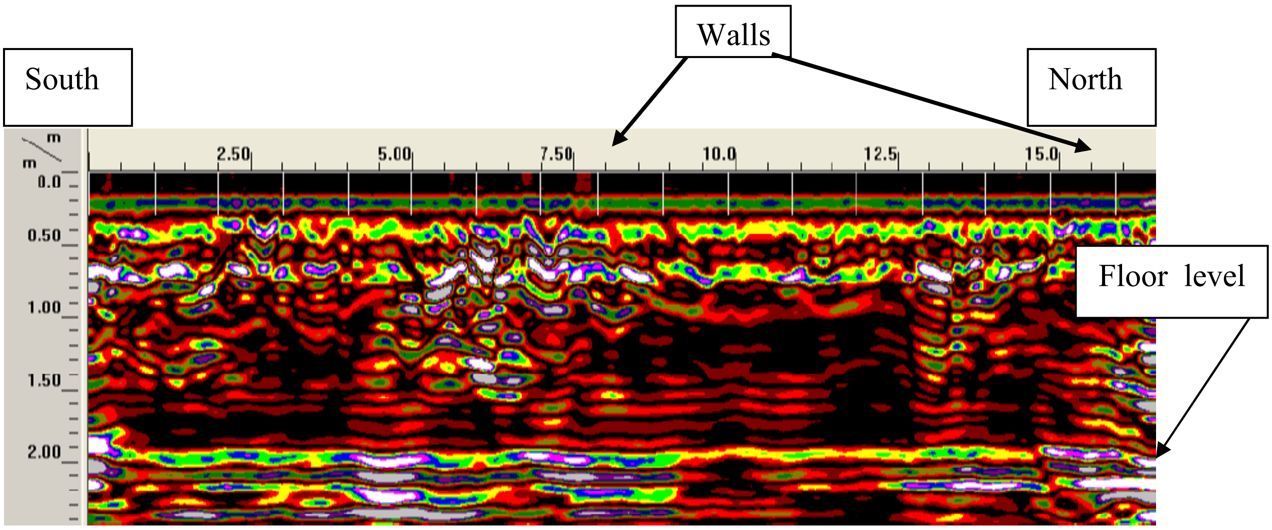

Figure 4.3 South- North GPR line 1 (L1N)

- Figure 4.4 shows line 2N (15.5 m long), which has a clear representation of the floor level located at 2m depth along the profile, multiple layers occur in this profile under the floor level and represent the cultural sequence in the study area, Greeks built the oldest layers then Roman empire began to develop the city by building their own city above Greek's floors. So in some profiles three layers are seen, the oldest layer refers to Greek period, then followed by Roman layer and the last newest layer belongs to Umayyad period. Scattered rocks can be seen at approximately 0.40m depth.

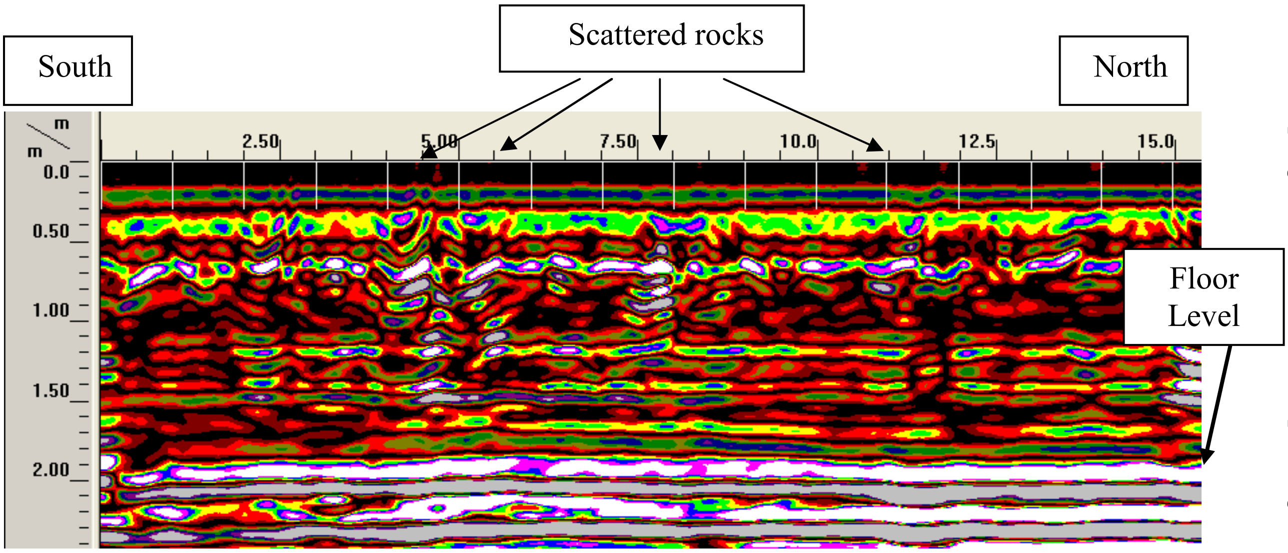

Figure 4.4 South- North GPR line 2 (L2N)

- Figure 4.5 shows line number 3 (15.75 m long). It was conducted from south to north. Small anomaly between distance 7.3m to 8m at 0.4m depth can be considered a small wall (or part of an ancient wall that could be partially destroyed by earthquakes). Another small part of a wall is found between distance 11.75m to 12.25m at 0.4m depth. A metal was found at 2.5 m distance and 0.4 m under surface. At 1.3m depth, an obvious disturbance occurs, this possibly happened due to some metallic anomalies nearby or it is shadows of the upper reflectors in this profile.

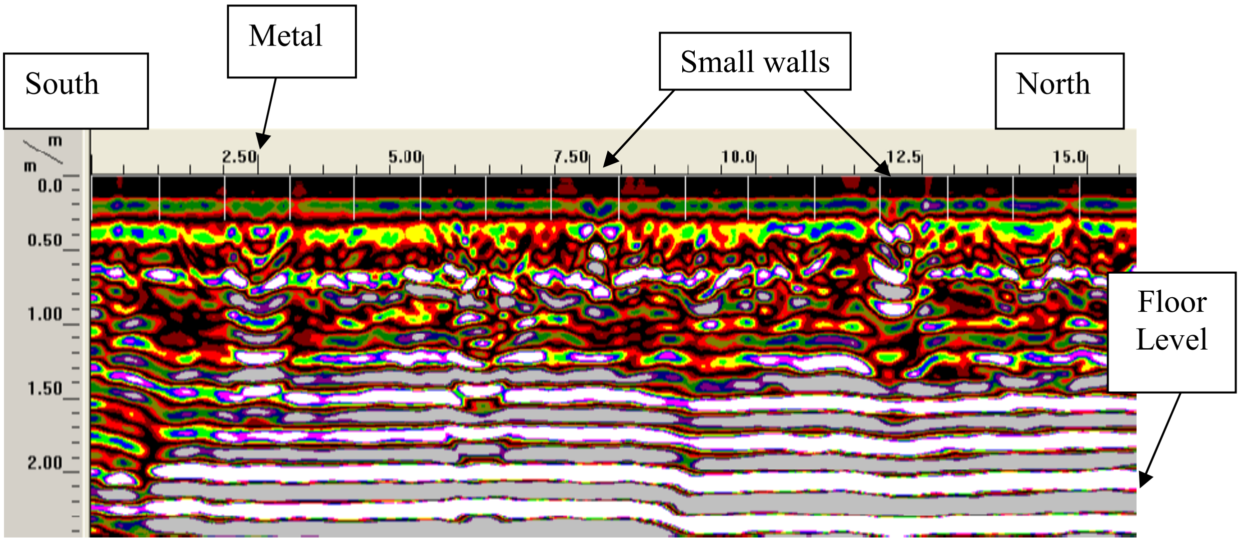

Figure 4.5 South- North GPR line 3 (L3N)

• Figure 4.6 shows line number 4 (16.64 m long). Approximately 0.10m under the surface and at 3.10m distance, an anomaly appears which was marked during field investigation as a small metal. Between 13m and 14.5m distance, at 0.30m depth, a wall is located. The Floor still in the same depth (2m) along the profile.

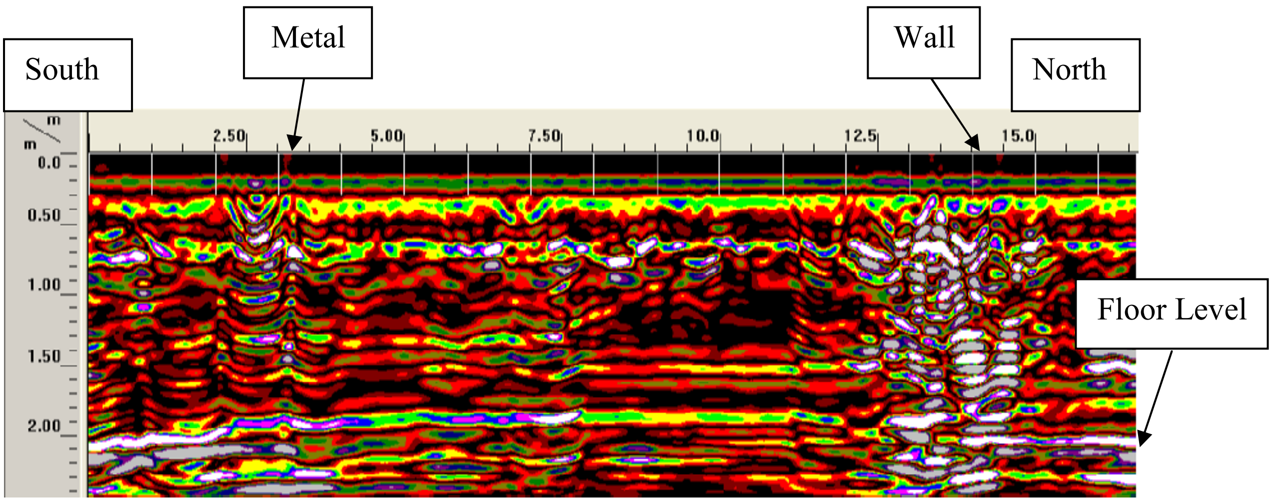

Figure 4.6 South- North GPR line 4 (L4N)

• Figure 4.7 shows line number 5 (16.73 m). It has two major anomalies, the first one is located approximately at 0.25 m depth and 10.2 m distance, this anomaly was seen during field surveys and it has been traced and recorded as shallow cable. The second anomaly was found between distances 11.85 m and 13.30 m which was located at 0.62 m under the surface, this implies that the target is elongated and it could be a buried wall. The floor is also found at 2 m depth along the profile.

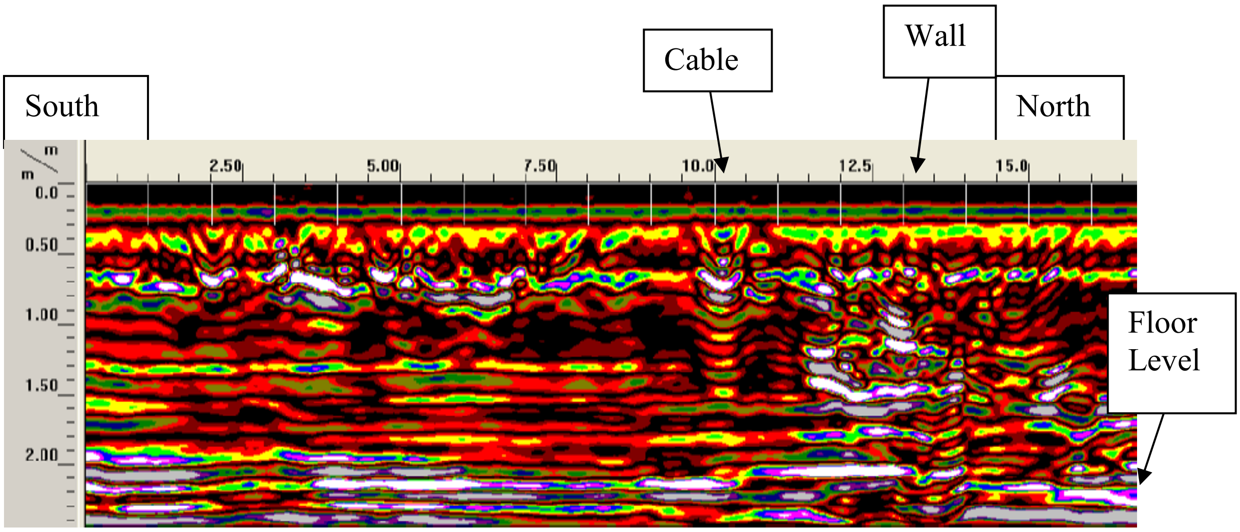

Figure 4.7 South- North GPR line 5 (L5N)

• Figure 4.8 shows line number 6 (16.36 m). Nothing significant was found except the cable, which is located at 0.35 m depth and 7 m distance. Scattered rocks are seen in this profile and they could be parts from destroyed walls that have been demolished by one of the ancient earthquakes that happened in the area. The floor level was deformed.

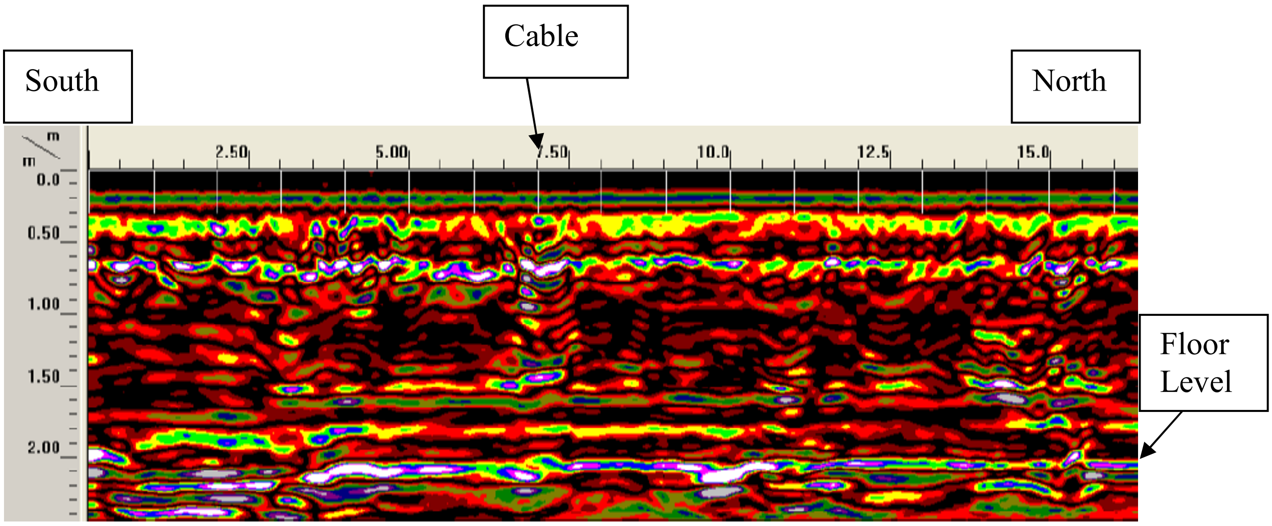

Figure 4.8 South- North GPR line 6 (L6N)

- Figure 4.9 shows line number 7 (16.58 m). The same previous cable extends from North- West to South- East in the study area. In this profile it's located in 3.5 m distance, 0.21 m under the surface. The floor level is not seen perfectly in this profile, but it can be followed and drawn.

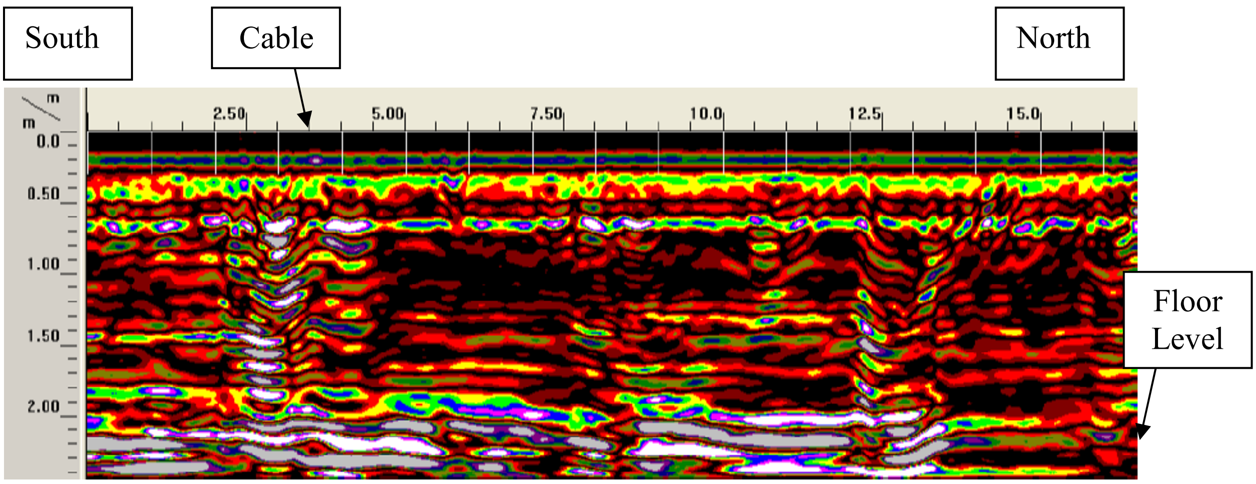

Figure 4.9 South- North GPR line 7 (L7N)

• Figure 4.10 shows line number 8 (16.81 m). The floor level is located between 2 m and 2.2 m depth. In some cases earthquakes cause subsidence in earth's surface, the shifting downward in floor level could be related to an earthquake.

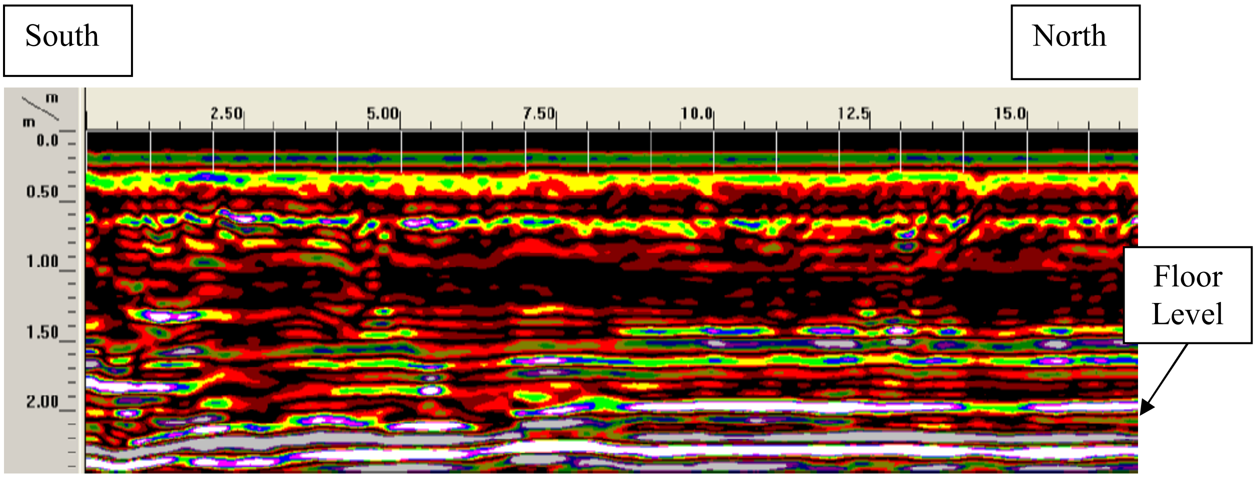

Figure 4.10 South- North GPR line 8 (L8N)

• Figure 4.11 shows line number 9 (16.41 m). In this profile, the floor is clearly noticed at 2 m depth. No major anomalies were found in this profile.

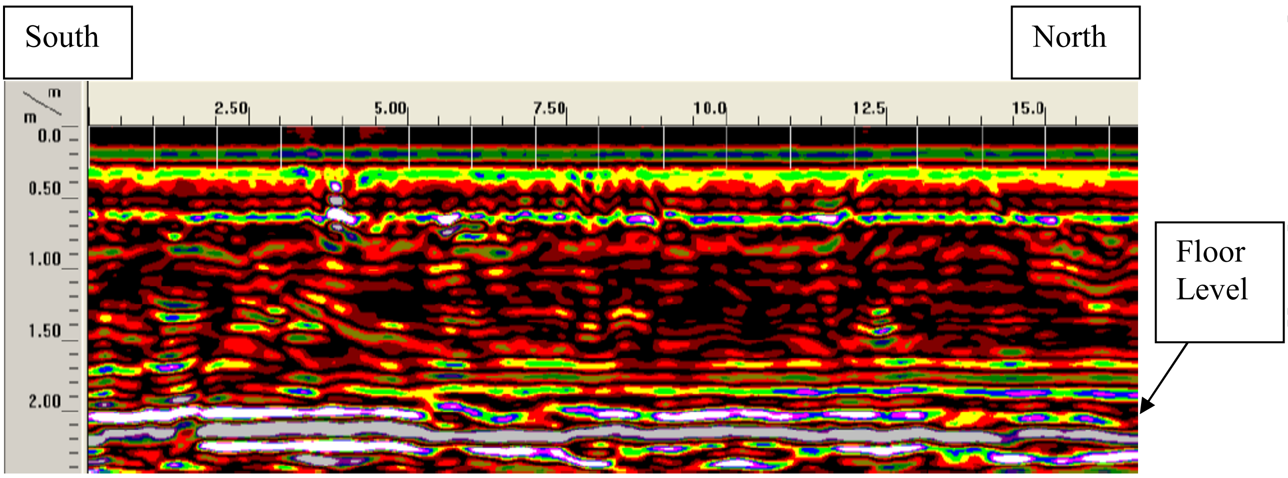

Figure 4.11 South- North GPR line 9 (L9N)

All South- North lines (L1N to L9N) were processed and interpreted as shown in the previous figures. Nine East- West lines (L1E to L9E) were conducted in the area. Only three of them were useful after processing (L2E, L5E and L8E) (Fig 4.2).

The results are briefly shown in the following figures.

- Figure 4.12 shows line 2 which was taken from East to West (14.8 m). Between 7.20 m and 11 m distance at 0.60 m depth, the anomaly could probably be a wall. Another wall between 13.5 and 14.8 m distance at 0.60 m depth was found (the walls are 3.8 and 1.3m long).

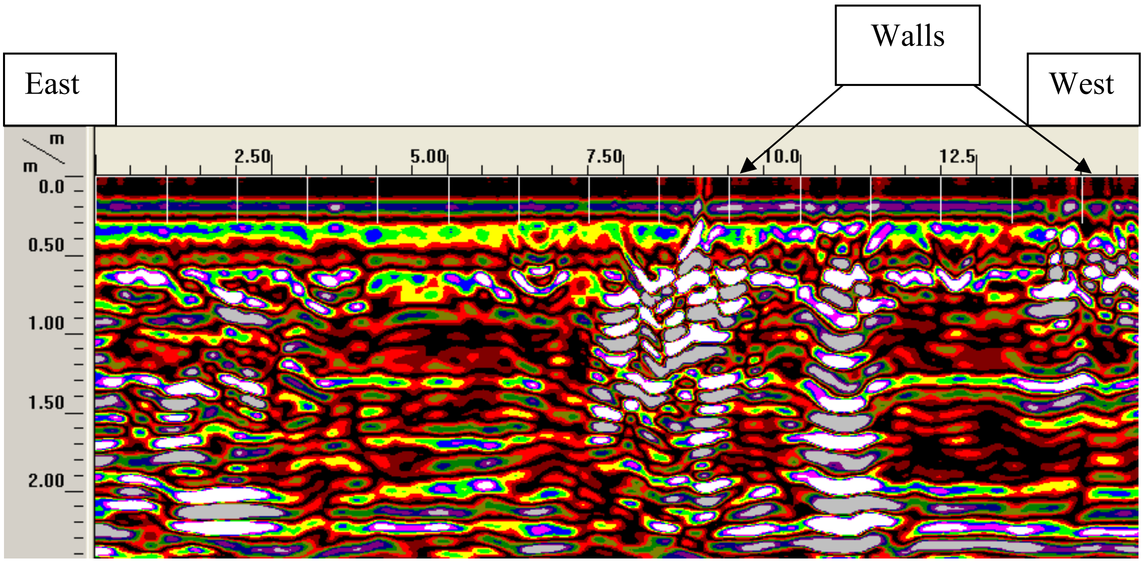

Figure 4.12 East to West GPR line 2 (L2E)

• Figure 4.13 shows line 5 which was taken from East to West (15.34 m). At 2 m depth along the profile, the floor was spotted. Between 9.9 m and 12 m distance, a wall was located at 0.6 m depth.

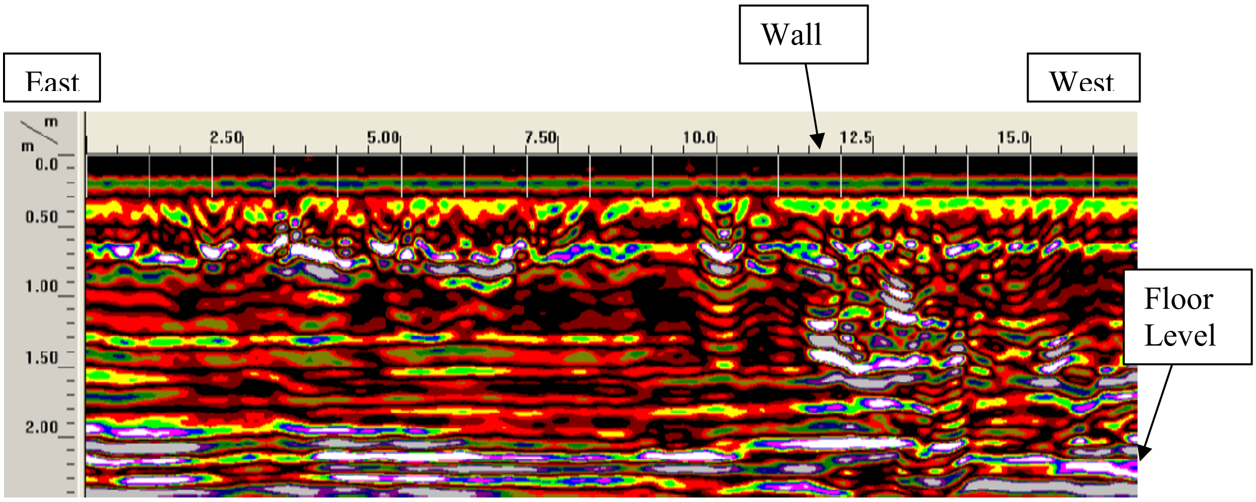

Figure 4.13 East to West GPR line 5 (L5E)

• Figure 4.14 shows line 8 which was taken from East to West (15.46 m). Several walls were located on this profile at 0.6 m depth, small wall was found between 0 m and 0.6 m distance, another one was located between 2.5 m and 4.15 m distance, the last wall was located between 9 m and 15.46 m distance (the wall is 6.46m long). The floor is found along the profile at 2 m depth.

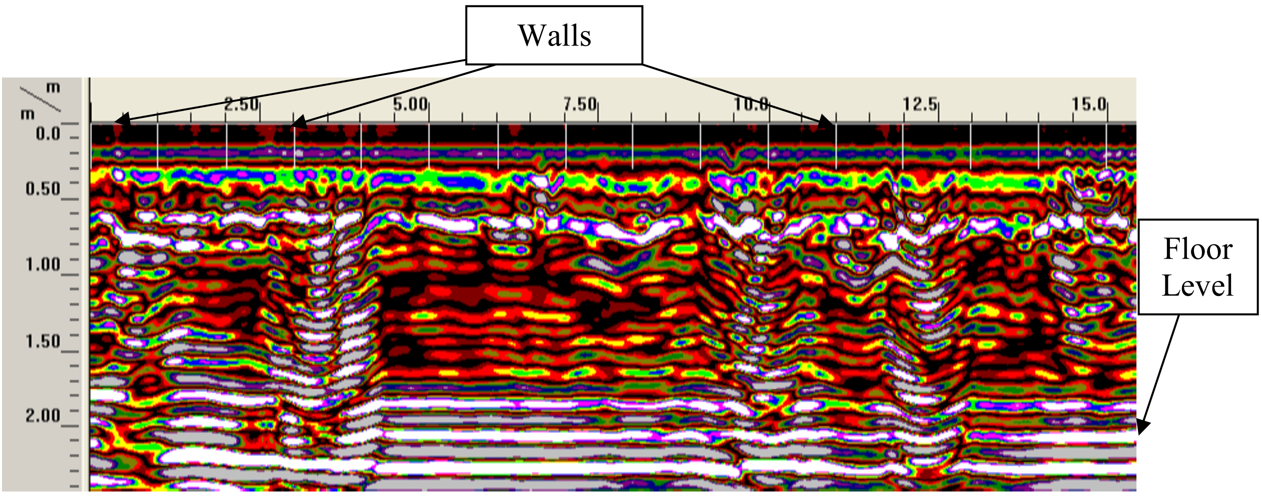

Figure 4.14 East to West GPR line 8 (L8E)

4.5 3D Models

3D models were made on the basis of the available georadar data and the data from the excavations. Georadar surveys and records the spatial position of the walls, floor level and metals. The results are representative of the contrast between target and the environment. After combining the results from interpreting the profiles, 3d models were done, they can be summarized by the following figures.

(All models were obtained using surfer software version 8, Golden Software Inc.)

- A model was obtained for the floor level. As figure 4.15 shows, The depth ranges between 2 m and 2.20 m. The floor surface shifts downward in some places, the ancient earthquakes did serious damage to the city, this subsidence could be one of those damages.

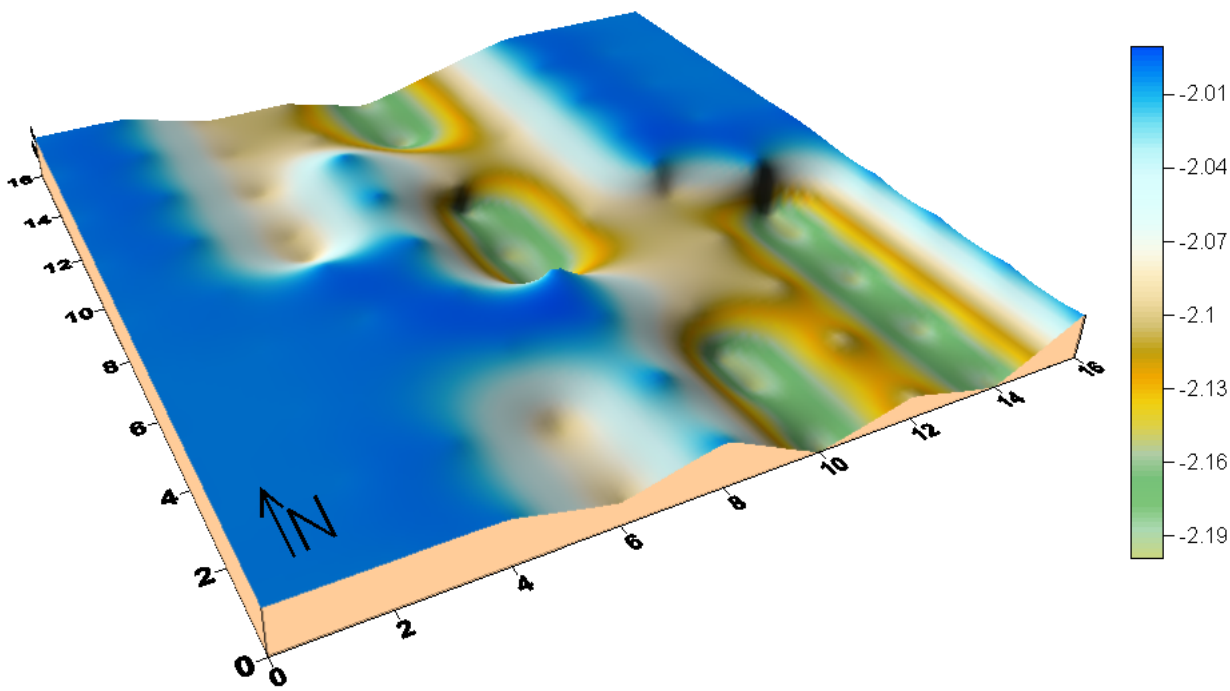

Figure 4.15 Floor level 3D model

• The second model shows the distribution of walls in the sturdy area (Fig 4.16). Main features were gathered while checking the model, corridors and rooms were found. The earthquakes damaged some walls in the area.

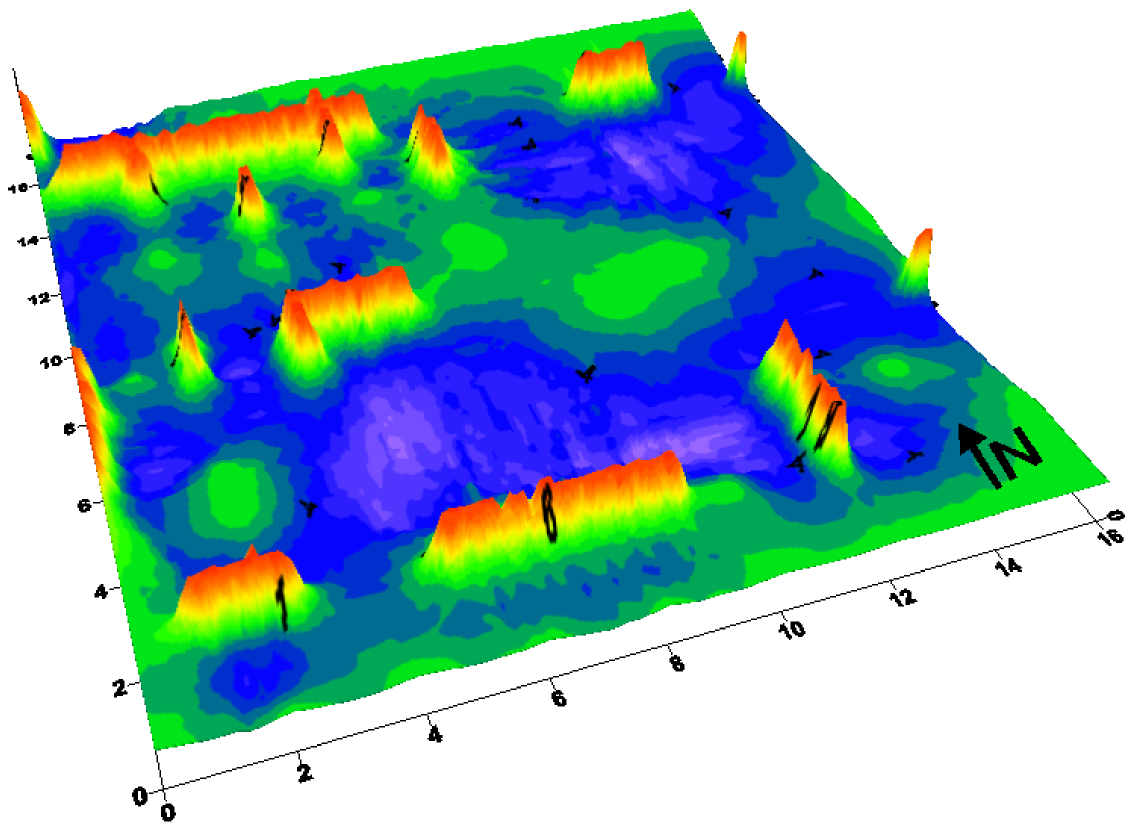

Figure 4.16 3D Model shows walls distribution

• The following model was produced after assembling the two previous models in a new one that shows the distribution of walls with the floor level (Fig 4.17).

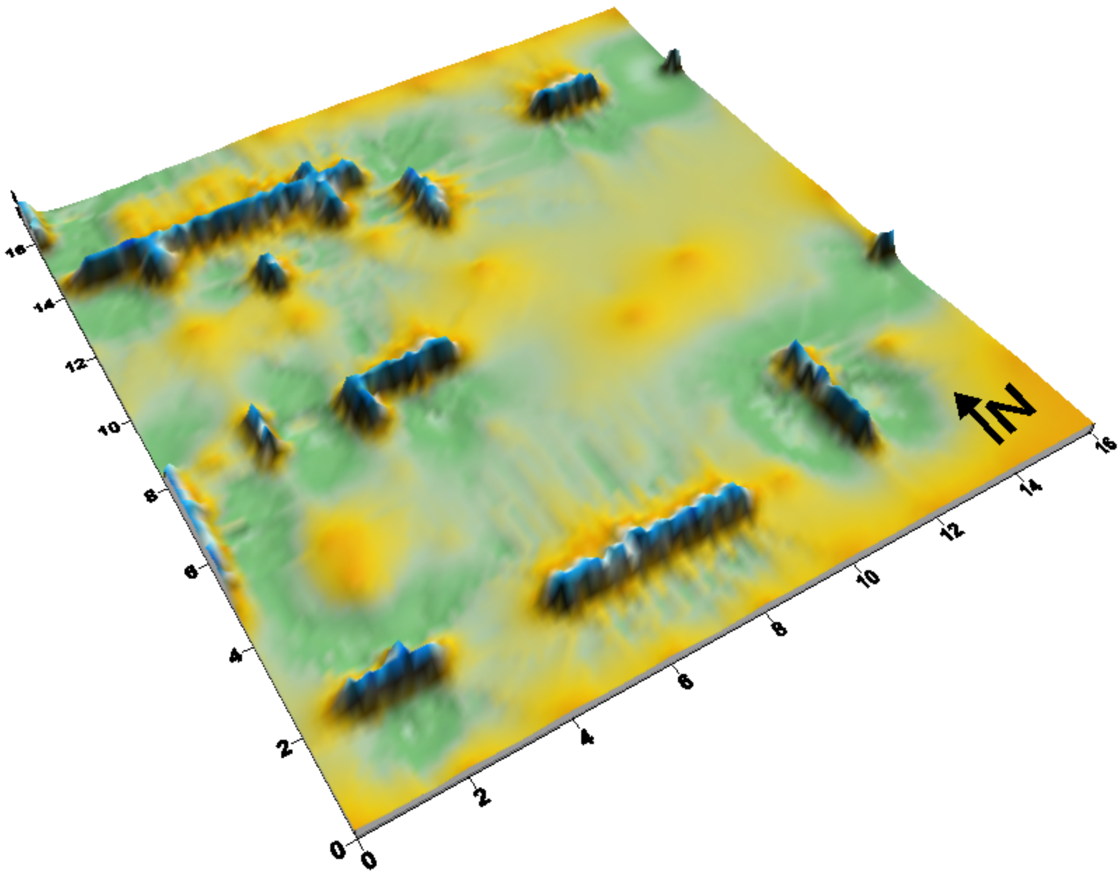

Figure 4.17 Walls + Floor 3D model

• A surface cable was found in the study area, it was marked during the field work and appeared in GPR profiles. Figure 4.18 shows the orientation of the cable in a new model. Figure 4.19 shows the effect of this cable over the area (energy dissipation), the software was helpful in minimizing this dissipation.

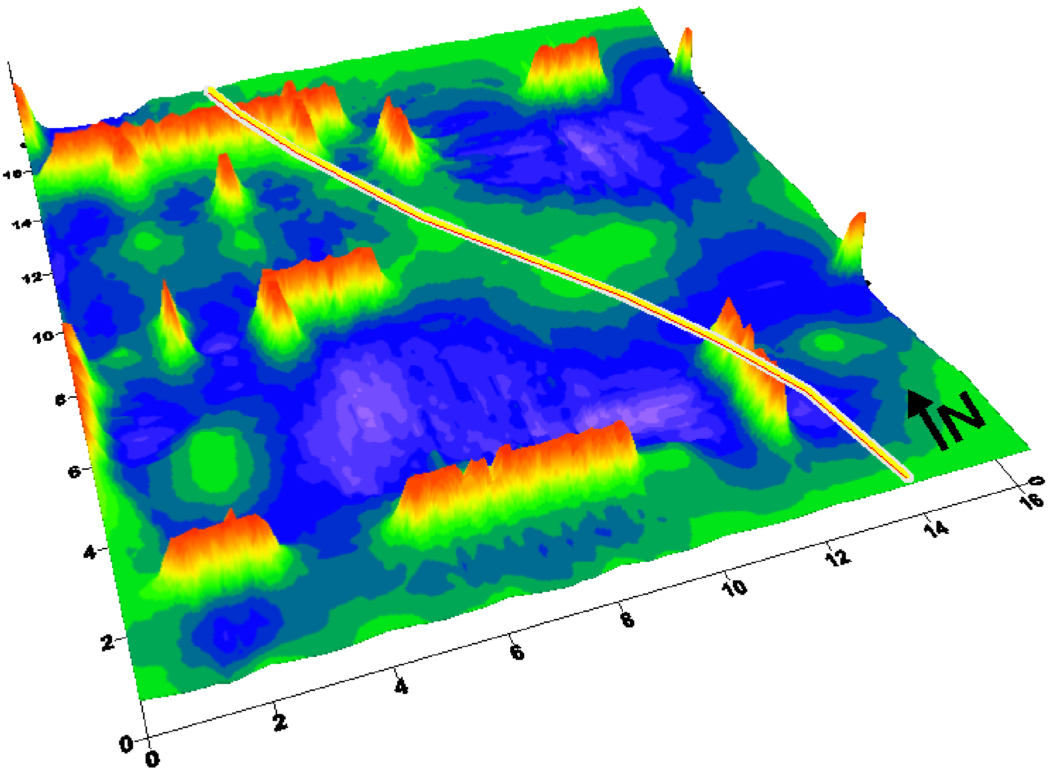

Figure 4.18 3D model showing the floor level, distribution of walls and the cable

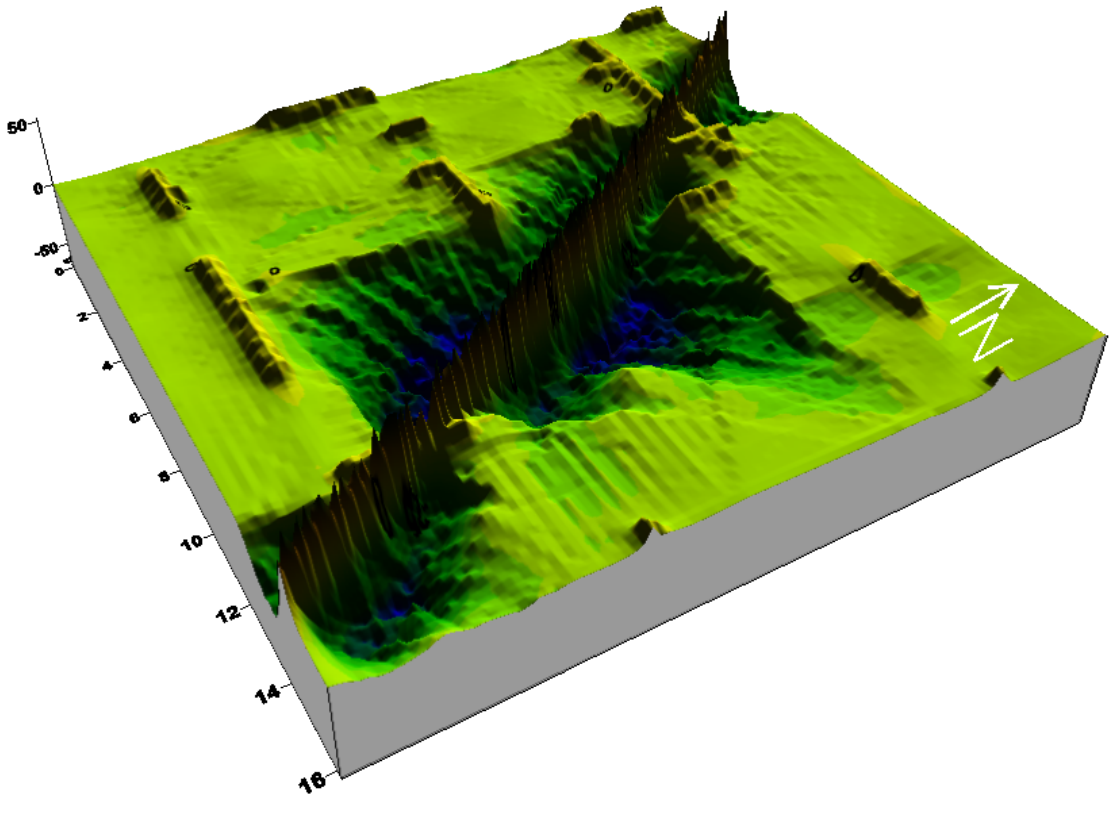

Figure 4.19 Energy dissipation around the cable

4.6 Discussion

The different types of anomalies were determined on the basis of the penetration velocity, the shape of hyperbolas (reflections shapes on the profiles) and the conductivity values.

The software classified the penetrated mediums into colored profiles according to the velocity that penetrate the underground different materials and distinguished between the anomalies (targets) by giving each specific type of anomaly a distinctive color.

The anomalies were located in the two dimensional profiles and appointed at distances and depths, the exact position of each anomaly (distance, depth) was recorded and drawn manually. The result was a primary sketch that reflects the distribution of walls, the depth of floor and the extension of cable over the study area.

The data were downloaded to Surfer software, then 3D surface models were created.

Structures of Islamic period were located all around the south Tetrakionion including the study area, fallen walls were related to historical earthquakes, this can significantly contribute to understanding active faulting and seismic hazards. This historical series of earthquakes caused serious destruction at the historical city of Jerash. Most of the city was destroyed, including the Umayyad mosque (Macro et al., 2003).

The models illustrated the buried Islamic features and the Roman and Byzantine underlying layers, the researches conclude that the southeast of the Tetrakionion (the study area) is an important building (administrative building) probably of Byzantine origin but with clear Islamic-period occupation (Walmsely, season report, 2008).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main conclusions of this study are:

1. GPR has lots of untapped potential, the results were unexpected but encouraging. The application of this technique in the historical city of Jerash expanded the perceptions for the future archaeological investigations.

2. Scanning the study area using GPR technique showed rooms and corridors attributed to the Umayyad period.

3. The Islamic period recorded tangible growth in the historical city of Jerash.

4. Historical sequence of earthquakes caused destruction in the historical city of Jerash. Fallen walls and destroyed buildings are evidences for these earthquakes .

5.2 recommendations

1. GPR proved to be helpful in archaeological investigations, while the method still not popular as it should be. GPR need to be examined in a wider range of applications.

2. Checking GPR limitations and problems and trying to use another compatible geophysical methods to support the surveys such as magnetic and resistivity.

3. Another antenna frequencies should be used and compared with 100 MHz antenna.

4. Extended investigations should be done in the unexcavated part of the historical city of Jerash.

REFERENCES

Abdelhamid, G., 1995. **The geology of Jarash area.** Natural Resources Authority, Amman, Jordan.

Abou Hamideh, K. (1996), **Geophysical Exploration In Archaeology Applications In Jordan.** Master dissertation, University of Jordan, Jordan.

Abou Karaki N., 1987, **Synthèse et carte sismotectonique des pays de la bordure orientale de la Mediterranée : Sismicité du system de failles du Jourdain - Mer Morte**. PhD Thesis, Université Louis Pasteur de Strasbourg, Institut de Physique du Globe, 417 p. (In French).

Abou Karaki, N. (2005), **Archeoseismology and Paleoseismology for the protection of Cultural Heritage and Archeological sites in the Middle East, The Impact of Large Earthquakes on the Archeological sites and cultural Heritage in the Middle east (Jordan, Lebanon, Syria, and Turkey).** The University of Jordan 2nd year's report, unpublished.

Abu-Jaber, N., al Saad, Z. and Smadi, N. (2009), **The quarryscapes of Gerasa (Jarash), Jordan.** Geological Survey of Norway Special Publication,12, pp. 67–75.

Al-Hanbali, N., Al Bayari, O., Saleh, B., Almasri, H. and Baltsavias, E., (2005), **Macro to Micro Archaeological Documentation: Building a 3D GIS Model for Jerash City and the Artemis Temple.** The fourth international conference on sciences and technology in archaeology and conservation, Amman-Zarqa, Dec 7-11.

Al Ruzouq, R., Al Zoubi, A., Abueladas, A. and Akawwi, E. (2011), **Hazard Mapping Along the Dead Sea Shoreline.** Hydrography and the Environment, Morocco.

Bashaireh, K., (2003) Provenance of marble and caliche used in the building of Um Qais (Gadara), NW Jordan. Unpublished M.Sc., Department of Earth and Environmental Sciences, Yarmouk University, Irbid, Jordan.

Bender, F. (1974), **Geology of Jordan.** Borntraeger, Berlin, 196 pp.

Castellaro, S., Imposa, S., Barone, F., Chiavetta, F., Gresta, S. and Mulargia, F. (2008), **Georadar and passive seismic survey in the Roman Amphitheatre of Catania (Sicily).** Journal of Cultural Heritage 9, 357–366, Elsevier.

Cezar, G. S., Rocha, P. L. F., Buarque, A. And Costa, A. (2001), **Two Brazilian archaeological sites investigated by GPR: Serrano and Morro Grande.** Journal of Applied Geophysics 47. 227–240

Conyers, L. (2004), **Ground Penetrating Radar For Archaeology.** Altamira, USA.

Conyers, L. (2006), **Innovative Ground-penetrating Radar Methods for Archaeological Mapping.** Archaeological Prospection 13, 137–139.

Cukavac, M., Klemčić, G. and Lazović, Č. (2008), **Reconstruction of buried objects by implementation of Ground Penetrating Radar technique: Example of Roman tomb in Brestovic (Serbia).** Publishing House "St. Ivan Rilski", Sofia, 333-338.

Daniels, J., J. (2000), **Ground penetrating radar fundamentals.** Prepared as an appendix to a report to the U.S.EPA, Region V.

Davis, J. L., and Annan, A. P., 1989, **Ground-penetrating radar for high-resolution mapping of soil and rock stratigraphy**. Geophysical Prospecting 37, p. 531-551.

Hruska, J. and Fuchs, G., 1999, **GPR prospection in ancient Ephesos.** Journal of Applied Geophysics 41. 293–312

Jol, H. M. (2009), **Ground penetrating radar: Theory and applications.** Elsevier Science.

Langfur, S. (2011), **Jerash (Gerasa).** Source: http://www.netours.com.

Leif, B., Sven, F. And Conny, S. (1983), **A radar in geological subsurface investigation.** Bulletin of the international association of engineering geology, 26-27.

Ludwig, R., Gerhards, H., Klenk, P., Wollschlager, U. and Buchner, J. (2011), **Electromagnetic methods in applied geophysics.** Institute of Environmental Physics, Heidelberg University.

Macro, S., Hartal, M., Hazan, N., Lev, L. and Stien, M. (2003), **Archaeology, history, and geology of the A.D. 749 earthquake, Dead Sea transform.** Geological society of America. Geology 31(8): 665-668.

Maksim Bano ,2000, **Imagerie de la proche surface par Géoradar, memoire** pour obtenir l'Habilitation à diriger des recherches de l' Université Louis Pasteur - Strasbourg , Spécialité : Géophysique Appliquée. 72 p.

Maksim Bano, M. and Girard, J. F. (2001), **Modeling of GPR reflections and water content estimation of moist soils.** EAGE 63rd Conference & Technical Exhibition, Amsterdam, the Netherlands.

Maksim Bano, Marquis, G., Nivie`re, B., Maurin, J.C. and Cushing, M. (2000), **Investigating alluvial and tectonic features with ground-penetrating radar and analyzing diffractions patterns.** Journal of applied geophysics 34, 33–41, Elsevier

Orlando, L. And Soldovieri, F. (2008), **Two different approaches for georadar data processing: A case study in archaeological prospecting.** Elsovier, Journal of Applied Geophysics 64 (2008) 1–13

Walmsely, A. (2008), **The Danish- Jordanian Islamic Jarash project season report**. University of Copenhagen

Willis B., 1928, **Earthquakes in the holy land**, BSSA,18, 72-105.

Willis B., 1933, **Earthquakes in the holy land - a correction**, BSSA, 23, 88-89.

Web. Sites

www.atlastours.net

www.jordan jubilee.com

www.malags.com

مسوحات باستخدام الرادار الأرضي ودراسة زلزالية جرش الأثرية، الاردن

إعداد
نور الحشحوش

المشرف
الاستاذ الدكتور نجيب أبو كركي

ملخص

لقد تم استخدام طريقة مسوحات رادار الإختراق الأرضي في هذه الدراسة، وهي طريقة جيوفيزيائية كهرومغناطيسية غير تدميرية تستخدم على نطاق واسع في الكثير من المجالات. تطبيق المسح الراداري في منطقة المسجد الأموي في جرش شمال الأردن دعّم الدراسة بتصور لتاريخ المنطقة غير المنقبة .

تم تثبيت احداثيات موقع الدراسة بوساطة تحديد المواقع الشامل وتمت دراسة المنطقة عن طريق مسح خطوط رادارية طولية ومتعامدة تغطيها ، وقد عولجت الخطوط وجمعت وفسرت بصور ونماذج ثلاثية الأبعاد توضح طبيعة التتابع الطبقي في منطقة الدراسة وما تحتويه من بقايا اثرية وثقافية.

الأطلال الاثرية في منطقة الدراسة تمثلت بجدران تعرضت لدمار جزئي من المحتمل ان يكون بفعل النشاط الزلزالي التاريخي الذي أتى على أجزاء كبيرة من المباني في تلك المنطقة وخاصة زلزال عام 749 للميلاد والواقع شمال وادي الاردن. الأطلال الأثرية المكتشفة تعود لمبنى إداري أموي قديم.

لقد اثبت رادار الإختراق الأرضي في المحصلة أنه من ضمن الطرق الجيوفيزيائية الفعالة المبتكرة في مسوحات المناطق الأثرية، لذلك ان من المهم التوسع بتطبيق هذه الطريقة وتعميمها أكثر لتشمل مجالات أوسع كاستخدامها في البحوث الجنائية والهندسية والمعالجة البيئية.